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► **To cite this version:**

O Fedaoui-Akmoussi, Laurent Molez, S Kaci, Raoul Jauberthie. Mechanical behavior and durability of fibre reinforced mortar in an aggressive environment. *Procedia Engineering*, 2015, 114, pp.445-452. 10.1016/j.proeng.2015.08.091 . hal-01196992

HAL Id: hal-01196992

<https://hal.science/hal-01196992>

Submitted on 10 Sep 2015

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1st International Conference on Structural Integrity

Mechanical behavior and durability of fibre reinforced mortar in an aggressive environment

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Abstract

This study was carried out to examine the mechanical behavior and durability of mortar with or without addition of silica fume, with and without steel fibre reinforcement. Three tests were carried out: strength, depth of pH reduction and micro-structural analysis by SEM. The mixes studied had two water cement ratios (0.5; 0.65); with a 0.5% steel fibre content and 10% silica fume content (in substitution of cement). To characterize the durability performance of the mortars studied, samples were exposed to one-year in three environments: wet environment (control samples under laboratory conditions, 20°C and 95% RH) and exposure samples: in cyclic environment (wetting and drying) and a sewage pumping station sump (an aggressive environment). SEM observations were carried out on samples to study the micro structural changes in the mortar's matrix. One sees the organic matter deposits located inside a pore and one can see the formation of the secondary ettringite. It is concluded that the compressive strength of the samples are relatively unaffected by mix type and environment. The samples exposed to sewage exhibited evidence a depth of pH reduction.

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Peer-review under responsibility of INEGI - Institute of Science and Innovation in Mechanical and Industrial Engineering

Keywords: Durability; microstructure; fibre mortar; silica fume; degradation; sewer.

1. Introduction

These last years we have seen a lot of degradation in wastewater systems [1, 2]. This can have a negative impact for hygiene humans, health and economy. To remake a sewerage is very expensive and hence the orientation of the solutions to repair. A low oxygen level in the wastewater can lead to the release of hydrogen sulphide gas, which

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can be oxidized to sulphuric acid in a bacterial layer; the acid with a pH of the order of 2 can produce deterioration of concrete by the dissolution of certain components of the cement paste and a sulphatic reaction which leads to the formation of expansive ettringite [3 - 6].

These reactions only take place in sections of the structure that are not permanently submerged. Deterioration is particularly aggressive in environments that are poorly ventilated (humid and elevated temperatures). The deterioration progresses from the exposed surface to the heart of the concrete; ultimately depassivation of the reinforcement can occur, further weakening the structure [7].

Durability depends essentially on porosity and cracking and therefore the compressive strength [8]; additionally the difference in the alkalinity of the interstitial solution and the exterior environment influences durability.

Previous studies have shown that the addition of fibres limit the development of cracks and can lead to an improvement in durability [9, 10]. Other studies have shown that the addition of silica fume contributes to not only a reduction in porosity but also an improvement in compressive strength; these two advantages potentially contribute to improving durability [11, 12]. In order to reduce the use of cement, we substituted 10% in mass of this last by the silica fume.

In this paper we presented the results of our study on the contribution of steel fibers and the substitution of cement by silica fume on the durability of the mortars in the various environments (wet, cyclic and sewers).

After an exposure period of one year in the different environments, the mechanical properties of samples were determined by the 3-point bending test on $4 \times 4 \times 16 \text{ cm}^3$, and by compression on cubes of $4 \times 4 \times 4 \text{ cm}^3$ of the mortars standardized with and without the addition of silica fume (MM and MFs) and of reinforced steel fibre mortars (MNfm and MFsfm). The durability characteristics were determined by measurements of the thickness of the concrete pH reduced by using phenolphthalein as an indicator and by observations under the Scanning Electron Microscopy in order to explain the different microstructural changes in the cement matrix.

2. Experimental Method

2.1. Materials

The cement used is a Portland cement CEM I 52.5, the Blaine specific surface area is $3600 \text{ cm}^2 \cdot \text{g}^{-1}$. The sand used is standard sand conforms to EN 196-1. The granulometric range is between 0.08 and 2mm. The steel fibres used are 25mm long and 0.25mm diameter (Fig. 1), their physical and mechanical properties are set out in Table 1. The fibre content used is 0.5% by volume of the mortar; this frequently used proportion enables good workability [13-14] and 10% (in substitution of cement) for the silica fume with 97.64% SiO_2 .

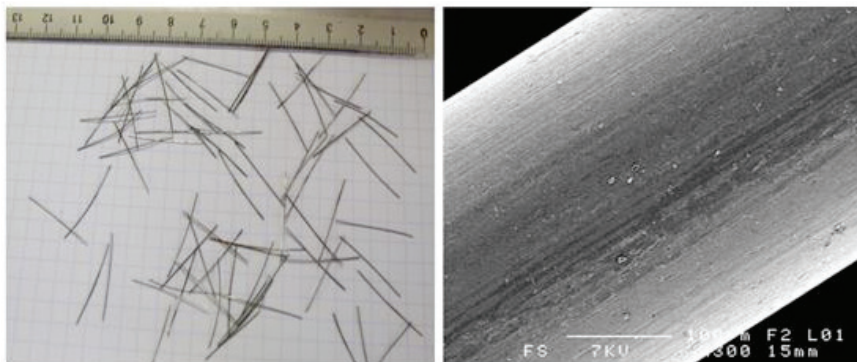


Fig. 1. The steel fibres used (left), SEM observation of fibre (right).

Table 1. Physical and mechanical properties of fibres.

Property	Steel fibre
Density (kg/m ³)	7800
Flexural strength (GPa)	1,3
Module of elasticity (GPa)	200
Fire resistance (°C)	1400
Expansion coefficient (µm/m)	11

2.2. Specimen preparation and testing

Four mortar mixes were used both complying with the standard (EN 106 – 1), the composition of the mortars is shown in Table 2. For each series of samples two water cement ratios were used 0.5 and 0.65.

Table 2. Mortars composition.

Components (kg/m ³)	MN		MFs		MNfm		MFsfm	
	0,5	0,65	0,5	0,65	0,5	0,65	0,5	0,65
W/C	0,5	0,65	0,5	0,65	0,5	0,65	0,5	0,65
Cement	494	460	443	412	492	458	440	410
Silica fume	0	0	49	46	0	0	49	46
Water	247	299	246	298	246	298	245	296
Sand	1483	1381	1475	1374	1476	1374	1468	1367
Fibres	0	0	0	0	39	36	39	36

After mixing 4×4×16 cm³ moulds were filled, compacted and stored in an environmental chamber at 20°C and 95% relative humidity (RH) for 24 hours. Once struck from the moulds, samples were conserved for a further seven days under the same conditions. Subsequently, the samples were stored in a chamber at 20°C and 50% RH to an age of 28 days. After the period of cure, to monitor the evolution of strength and durability characteristics, one series of samples was placed in a sewage pumping station sump, mid-way between high and low water levels. The second series of samples was subjected to cycles of wetting and drying under laboratory conditions; 8 hour cycles – 4 hours in water 4 hours drying, that is to say 3 cycles per day, in total 1100 cycles. The control series were placed in the wet environment (20°C and 95% RH). At an age of 365 days samples were recovered for testing: Three point flexural tests and compression tests were carried out. The depth of pH reduction was measured after failure by spraying the freshly fractured surface with a solution of phenolphthalein which revealed the depth of pH reduction in the mortar. Finally, observations by scanning electron microscopy (SEM) were carried out on samples to visualize the modifications to micro-structure.

3. Results and Discussion

3.1. Strength Characteristics

The stress at failure was determined in compression for the various water cement ratios (Fig.2). So we plotted curves efforts-displacement 3 point bending for different water cement ratios which were presented in Fig. 3 and Fig. 4. The results relate mortars conserved for a year in the different environments.

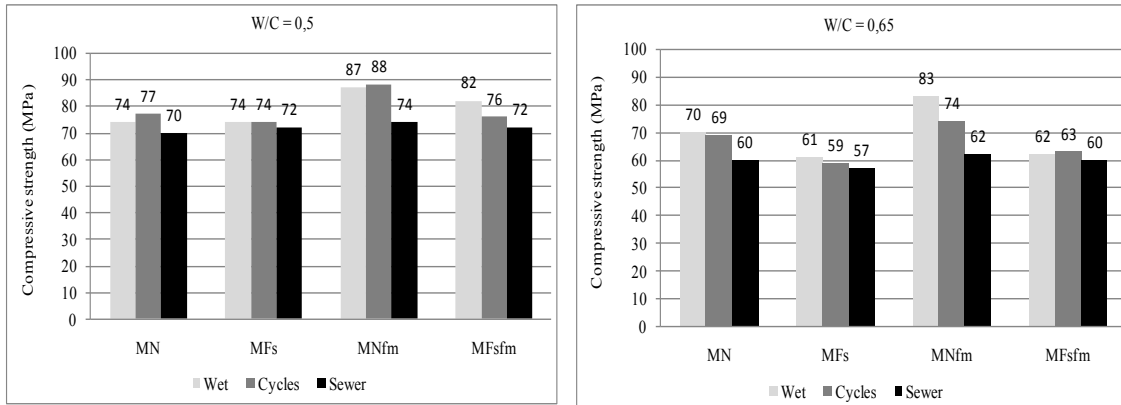


Fig. 2. Compressive strength of the mortars.

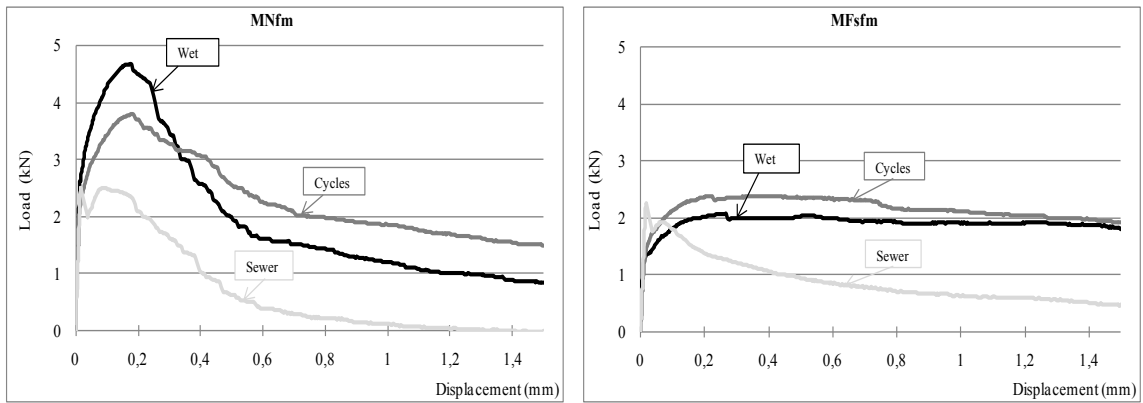


Fig. 3. Force-displacement curves for W/C = 0,5.

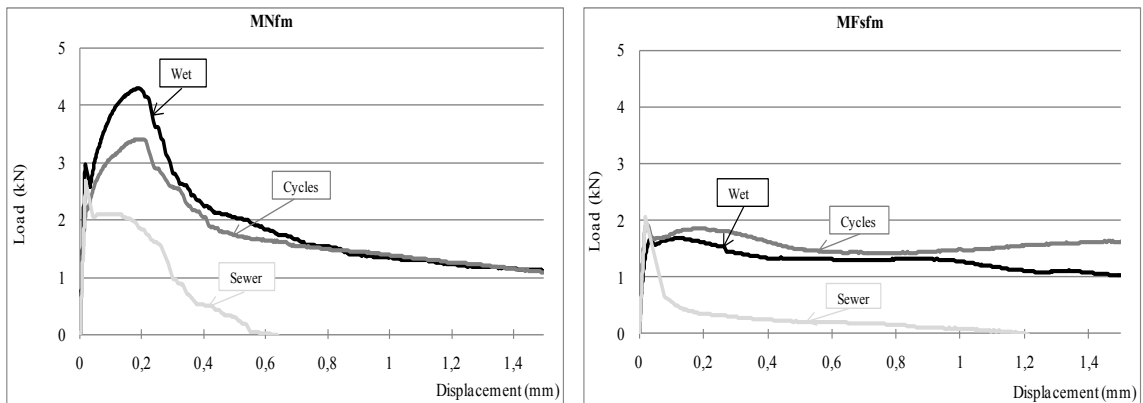


Fig. 4. Force-displacement curves for W/C = 0,65.

With regard to the compressive strengths: the mortar with fibres (MNfm, MFsfm) showed slightly higher strengths, when compared with the same mortars without fibres (MN, MFs), for all water cement ratios and environments. It is observed that the mortar with silica fume have slightly lower strength compared to mortar without silica fume.

The flexural strength of the MNfm and MFsfm mortars was lower than the MN and MFs mortars. These samples have been exposed to aggressive agents in the sewer; the steel fibres have corroded and suffer a loss in section and consequently a reduction of physicochemical characteristics; this has also resulted in an increase in porosity and surface cracking with a consequential reduction in flexural strength. On the basis of these observations it is noted that the use of steel fibres in a wastewater environment may have a detrimental effect on performance except if the fibres are well coated. The ductility of the mortars with silica fume is better compared to the mortars without silica fume in the sewer environment.

3.2. Phenolphthalein Test

The depth of pH modification of the mortar was determined by the phenolphthalein test (color indicator); a sprayed solution turns pink if the pH is greater than 9 which allow the visualization of the modification to the mortar. Five measurements were taken from each face of the sample, ignoring the measurements at the corners; this allowed a mean value of 20 reading for each sample. Fig. 5 sets out the average depth of pH reduction and Fig. 6 shows examples of the fractured surfaces treated with phenolphthalein.

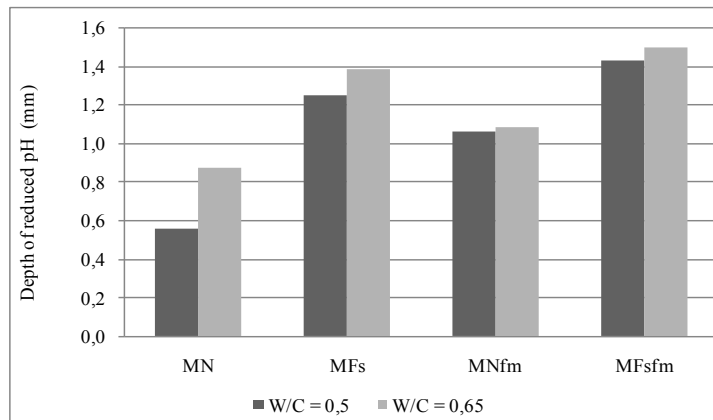


Fig. 5. Depth of pH change of the samples stored in sewers.

All the samples preserved in the wet and cycles environments do not have a depth of pH reduced. As against those stored in sewers have a depth of pH reduced which varies according to the W/C ratio for the Four types of mortar (mortar without silica fume (MN, MNfm) and mortar with silica fume (MFs, MFsfm)).

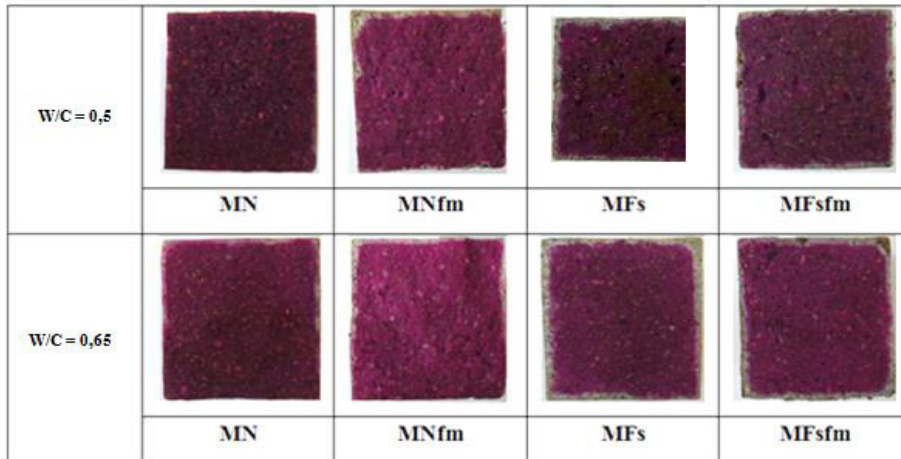


Fig. 6. pH modification detected by spraying with phenolphthalein.

The depths of pH alteration in the samples exposed in the sump are significant. It is normal that the humidity in a closed space such as a sump would be high, a condition not favouring carbonation. Given the reduced portlandite content in the mortars and the high humidity it is suggested that carbonation is not the reason for the reduction in pH. It is probable that bio-chemical effects are responsible for the alterations to the external mortar surface under sewer conditions; SEM images show organic inclusions and bacteria within the surface layers of these mortars, thus supporting the hypothesis that bio-chemical modifications have taken place in the surface layer of the mortar.

The depth of pH alteration obtained on the mortars with silica fume are more important than those obtained on the mortars without silica fume, thus the presence of silica fume did not slow the progress of the front reduced basicity. One notes that there' is a slight increase in the depth at pH reduced for the mortars fibers compared to those without fibers, this can be explained by the fact that on the external surface of the specimens some fibers remained visible, they have favored access to the aggressive solution.

3.3. SEM Observations

Observations by scanning electron microscope (SEM) are shown in Fig. 7; these observations were restricted to the mortars with silica fume preserved in the sewer in order to better analyze the various modifications of the microstructure.

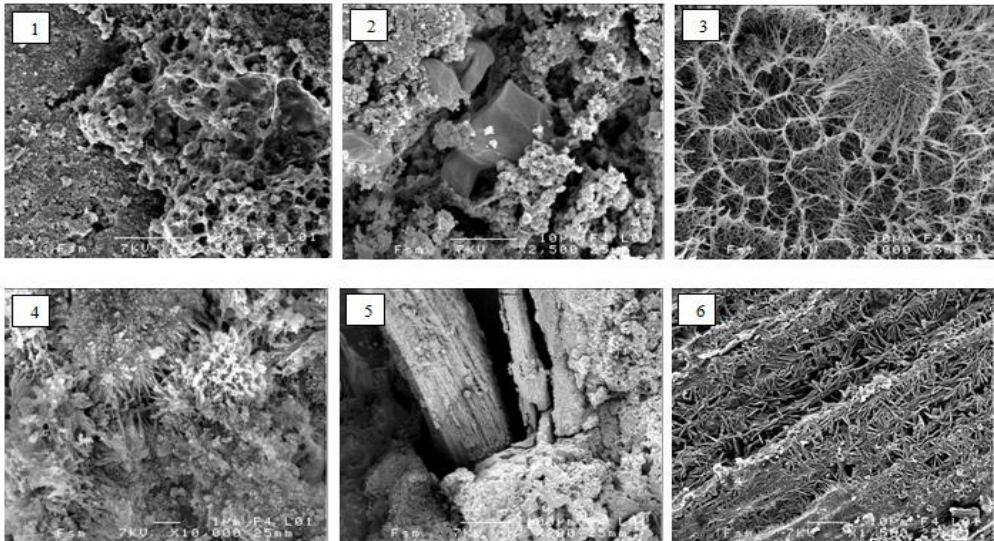


Fig. 7. SEM observations.

Fig. 7 presents the aspect of the various formations microstructural of the matrix. On the photograph (1) and (2), one sees the organic matter deposits located inside a pore and the aspect of degraded mortar. The photograph (3) and (4) illustrate respectively the formation of the secondary ettringite and the aspect of C-S-H degraded. The aspect of fibre in contact with the sewer environment is shown in photographs (5) and (6). Judging by the SEM images the corroding front appears to be quite complex, pockets of ettringite and bacteria have both been observed. Ettringite is stable at a pH above about 10.7, consequently as the corrosion front progresses the pH will reduce and the ettringite will decompose to gypsum and Al hydroxide. The evidence of bacteria existing in the matrix would suggest that locally the pH has fallen to allow the existence of neutrophilic thiooxidans.

4. Conclusion

The results of this study, after one year of conservation in the sewer environment, show us that the addition of the silica fume for the various studied mortars does not improve their mechanical behaviors. The compressive strengths of the mortars preserved in different environments are appreciably the same ones.

For bending, the fibers mortars (MNfm, MFsfm) stored in the sewer environment present a reduction in resistance compared to those stored in the wet and cyclic environments. This decrease can be explained by the early corrosion of the steel fibers, which in the end do not participate to the tensile strength, observations confirmed by SEM.

The depths of pH change obtained by the mortars with silica fume are more important than those obtained by the mortars without silica fume; therefore the presence of the silica fume does not slow down the advance of reduced basicity front. This is not due to the carbonation because the sewer environment is a closed and humid environment. So it is likely that this change is due to biochemical effects that are responsible for these alterations to the external surface of the mortar.

The SEM observations revealed: superficial degradation mortar which progress inwards leading to secondary ettringite formation and the presence of degraded C-S-H.

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