Understanding concrete biodeterioration mechanisms and resistance in sewer environments: recent progress and scientific and technical challenges

Alexandra Bertron[1,*], *Amr* Aboulela[1,2], *Amaury* Buvigner[1,2], *Matthieu* Peyre Lavigne[2] and *Cédric* Patapy[1]

[1]LMDC, Université de Toulouse, UPS, INSA Toulouse, France
[2]TBI, Université de Toulouse, CNRS, INRA, INSA, Toulouse, France

Extended abstract

The durability of concrete in sewer systems notably related to the biogenic acid attack is a major economic, societal and health issue in developed and emerging countries. Strong deterioration occurs in the aerial part of the pipes because of biological activity and notably the production of sulfuric acid by sulfur oxidising bacteria (SOB) developed in the biofilm in direct contact with the concrete surface.
There are several major scientific and technical challenges to develop durable and sustainable cementitious materials intended for the construction of new sewer systems, but also for the maintenance and rehabilitation of old ones, and adapted to different level of aggressiveness encountered in the sewers. Calcium aluminate cements (CAC) have proven high resistance in sewers compared to Portland-cement based (PC) materials, the reason for their resistance (biological, chemical) still being discussed. More generally the intrinsic characteristics, particularly chemical and mineralogical, of cementitious materials, which are responsible for their resistance to the biogenic acid attack in sewerage systems, are not yet fully understood. Also, few studies in the literature investigated the resistance of low-CO_2 cementitious materials to the biogenic acid attack so far. To make progress on these various issues, the question of the assessment of cementitious materials in laboratory using representative and accelerated biological tests is also crucial, as notably chemical tests, currently prescribed in some standards, were proven not to be relevant in some conditions.

The presentation will aim to review the latest progress obtained from the work carried out at INSA Toulouse in the last decade, (i) in the understanding of the mechanisms of biodeterioration and of the resistance of cementitious materials exposed to sewer-like environments, and (ii) the development of a representative accelerated laboratory biological test method (BAC test) [1–3] together with a universal performance indicator and (iii) their exploitation to assess the performances of a wide range of cementitious materials in such conditions.
The studies investigated different types of binder systems, including conventional binders, PC-based cements, and CAC, and low-CO_2 binders (blast-furnace slag cements (BFSC), calcium-sulfoaluminate (CSA) and alkali-activated (AA) based binders). In order to identify the key factors responsible for the resistance of cementitious materials in sewer, a comparative evaluation of cementitious materials made of CAC, PC, BFSC (PC with 30 to 95% of slag), CSA and AA-based binders exposed to sulfur-oxidizing microbial activity in different conditions, was carried out.

Firstly, a possible mechanism often argued in the literature to explain the better resistance of CAC binders is the bacteriostatic effect on SOB linked to their aluminium leaching. Nevertheless, reactor tests conducted on acidophilic SOB, demonstrated their ability to acclimatise to high aluminium contents [4]. More generally, the nature of the material (CAC, PC, BFSC, CSA and AA-based binders) did not significantly affect the SOB selection on the surface of paste specimens exposed to the BAC test [5,6]. Moreover, the CAC materials seemed to favour the development of a higher SOB activity (and so acid production) than PC-based systems, leading to more aggressive conditions. The resistance of CAC materials to biodeterioration appeared to be mainly linked to the intrinsic chemical

* Corresponding author: bertron@insa-toulouse.fr

resistance of mineralogical phases initially present or precipitated during the deterioration process (AH_3). Reactive transfer modelling using a home-made model developed on Aquasim software, showed that the transport phenomena limiting the dissolution of the cement matrix seemed to constitute a secondary process in the conditions of the BAC test [5,7].

Besides the very good resistance of calcium aluminate cement, certain calcium sulfoaluminate cement (CSA)-based materials have shown better behavior than Portland cements in the experimental conditions of the BAC test.

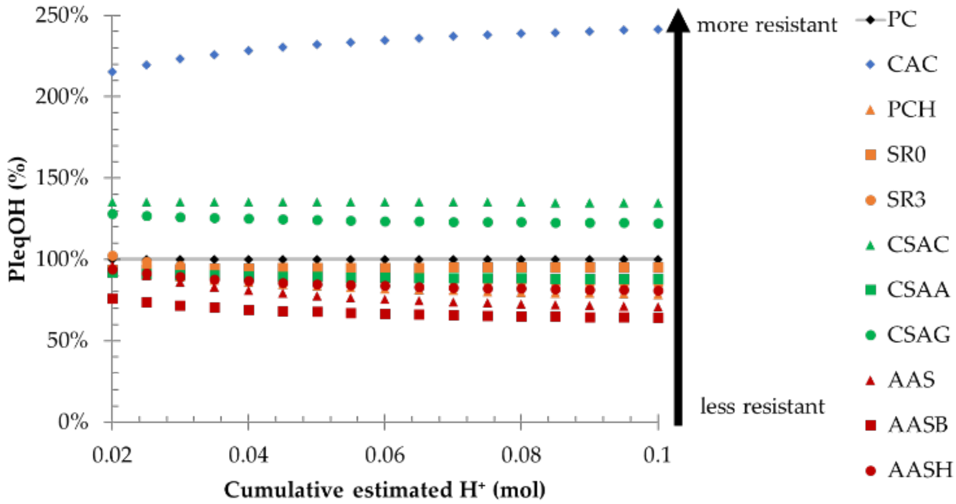

Fig.1. Equivalent OH Performance indicator (PIeqOH) of cement pastes made with different binders and exposed to the BAC test, as a function of the cumulative leached sulfate (presented as estimated H^+, as H_2SO_4 is produced by the sulfur oxidizing microorganisms developed on the surface of the materials) in the leached solution of the BAC test [8]. The performance indicator (PIeqOH) is an indicator that assesses the resistance of cementitious materials tested in the BAC test compared to the reference material (Portland Cement based paste). Such indicator allows a classification of cementitious materials according to their resistance to biological attack in sewer conditions assimilated by the accelerated laboratory test. It is based on the evaluation of the leaching of chemical cementitious ions (in particular calcium, aluminium, iron, magnesium and sulfate) which define the neutralizing capacity of the materials. The novelty and interest of the indicator is that it allows to compare a range of materials with very different mineralogical and chemical natures. SR0 and 3: Sulfate resistant cements, PCH: Portland cement with iron rich addition, AAS, AASH and AASB: alkali activated slag alone, with iron or aluminium rich additions. The meanings of the other acronyms are provided in the text.

Calcium sulfoaluminate clinker (CSAC) and calcium sulfoaluminate clinker with gypsum (CSAG) showed better performance than calcium sulfoaluminate clinker with anhydrite (CSAC) (**Error! Reference source not found.**). The evolution of the mineralogical phases of the three studied CSA-based materials consisted of the dissolution of AFt and AFm phases and the formation of gibbsite-like AH_3 on the surface. The better resistance of CSA-based materials was mainly attributed to the presence of aluminium hydroxide (AH_3) as well as its chemical stability in acidic environments. Moreover, the mineralogical form of aluminium-bearing phases was a key factor in the resistance of such phases; i.e. the increase of the aluminium content in the materials by non-reactive mineral additives was shown to be insufficient to improve the performance of cementitious materials.

The presentation will finally review the pending questions and research needs for further years to develop more durable and low-environmental impact sewer structures. They are notably related to (i) which form of aluminium based phases should be promoted in low-CO_2 binders to increase their resistance to biogenic acid attack, (ii) the relation between environmental conditions in sewer pipes (including the H_2S concentration, the relative humidity, and the amplitude and frequency of their variations, the geometry of the sewer, etc.) and the aggressiveness of the environments, and how to consider them in the classification of the aggressiveness of sewer networks, and in the recommendations on material's design. (iii) We need also to establish reliable correlations between the rate of deterioration of the laboratory tests and on-site situation.

The authors acknowledge the financial support of FUI Duranet (BPI France), Saint-Gobain Pont-à-Mousson, LafargeHolcim, and the Institut Universitaire de France (Junior Member award A. Bertron).

References

1. A. Aboulela, M. Peyre Lavigne, et al., Materials. 14 (2021) 686. https://doi.org/10.3390/ma14030686.

2. M. Peyre Lavigne, A. Bertron, et al., Cem. Concr. Res. 73 (2015) 246–256. https://doi.org/10.1016/j.cemconres.2014.10.025.
3. M. Peyre Lavigne, A. Bertron, et al. Cem. Concr. Res. 79 (2016) 409–418. https://doi.org/10.1016/j.cemconres.2015.10.002.
4. A. Buvignier, M. Peyre-Lavigne, O. Robin, M. Bounouba, C. Patapy, A. Bertron, E. Paul, Appl. Environ. Microbiol. (2019) AEM.00302-19. https://doi.org/10.1128/AEM.00302-19.
5. A. Buvignier, PhD thesis, INSA Toulouse, 2018, https://www.theses.fr/232931054.
6. A. Aboulela, M. Peyre Lavigne, T. Pons, M. Bounouba, M. Schiettekatte, P. Lepercq, M. Mercade, C. Patapy, S. Meulenyzer, A. Bertron, Sci. Total Environ. 850 (2022) 158031. https://doi.org/10.1016/j.scitotenv.2022.158031.
7. A. Buvignier, C. Patapy, M.P. Lavigne, E. Paul, A. Bertron, Cem. Concr. Res. 123 (2019) 105785. https://doi.org/10.1016/j.cemconres.2019.105785.
8. A. Aboulela, PhD thesis, INSA TOULOUSE, 2022. http://www.theses.fr/s246951