

PhD position 2024

3 years, starting October 2024

Subject :	Development of decarbonated excavable materials composed of recycled concrete aggregates consolidated by bio-carbonation in substitution of the binder
Organisation :	University Gustave Eiffel – https://www.univ-gustave-eiffel.fr/
Scientific section:	Civil engineering ; microbiology
Keywords :	Recycled concrete aggregate, calcium carbonate, bio-precipitation, low-carbon binder
Laboratory :	Département “Matériaux et Structures” (MAST), Laboratoires (CPDM) et (MIT)
Location :	Université Gustave Eiffel, Campus de Marne-la-vallée (77) et Nantes (Bouguenais, 44)
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Project and job description

The development of electric vehicles and autonomous vehicles requires the equipment of infrastructure with different types of sensors, and the installation, if necessary, of inductive or conductive charging systems. Companies are also proposing new lighting and dynamic signage solutions integrated into infrastructures, and finally, solutions for harvesting energy through infrastructures are being developed. All these technological

developments make road infrastructures more complex and modular construction appears to be a solution for the future. Indeed, this construction method allows the prefabrication in factory of elements integrating all the necessary functional elements. In an urban environment, the modular nature of the structure also allows access to the underlying networks, which facilitates maintenance. This is, for example, the purpose of removable urban pavements developed on the basis of hexagonal concrete slabs for several years at the G. Eiffel University [1]. To achieve this, the platform on which the modular elements are placed must be easily excavated and therefore of low strength, while having sufficient bearing capacity to bear the traffic. A priori, these two properties are antinomic. However, the Gustave Eiffel University has developed for a few years a method for the mix design of such cement-based materials through the theses of Morin (2009) and Genesseeux (2015), [2,3]. These materials have two disadvantages from an environmental point of view: they contain cement, the manufacture of which releases CO₂ (cement accounts for about 7% of global CO₂ releases) and they consume natural aggregates that are not available in urban areas and require transportation.

Conventional urban roadways are very regularly opened for network maintenance. The backfilling of these trenches is generally done with unbound granular materials which are compacted. This compaction leads to significant noise pollution during urban works and often does not avoid post-compaction settlement, which causes discomfort, rolling noise and is detrimental to the aesthetics of urban centers. Self-compacting cement-based materials exist but are rarely used because it is difficult to control the long-term excavatable nature of these materials.

These problems are all the more marked as, in the road sector, the volumes concerned are significant. It is therefore important to overcome these disadvantages and propose a decarbonated excavatable construction system.

For that, the objectives of this thesis are:

- To substitute natural aggregates by recycled concrete aggregates;
- To substitute the cementitious binder by calcium carbonates precipitated by micro-organisms. The reuse of recycled concrete aggregates is a solution to reduce waste in the construction industry, but its reuse in new concrete remains moderate.

The ability of bacteria to induce the formation of calcium carbonate has several applications:

- the self-healing of concrete [4]: the bacteria introduced in the form of spores in the concrete are activated at the level of micro-cracks (<1 mm) and fill these cracks;
- renovation of natural stone monuments [5]: the bacteria form a protective film of CaCO₃ on the surface of the stone;
- soil consolidation [6]: the bacteria are injected into the soil and the calcium carbonate formed cements the grains;
- improvement of recycled concrete aggregates: the objective is to reduce the porosity of recycled aggregates by forming a carbonate biofilm on their surface. This application is still in the field of research, in particular at the G Eiffel University [7,8].
- The formation of bricks with the use of CaCO₃ to bind sand grains together [9,10].

This work is therefore part of the development of an innovative mobility, more respectful of the environment and more involved in the circular economy. The applications could first be dedicated to the existing market of urban trenches and then to modular pavements if the technique develops.

The scientific keys to overcome in this work are multiple:

- identification of bacteria adapted to recycled aggregates
- control of rapid bacterial development and calcification over the thickness of the material layer in the laboratory;
- characterization of the intergranular bond by bacteria and identification of the influencing factors;
- optimization of the obtained excavability/ bearing capacity obtained ;
- scaling of the laboratory process to the site;

- analysis of the life cycle of the selected solution and conclusion on the technical and social interest of the solution.

References

[1] <http://cud.ifsttar.fr//>

[2] Genesseaux E., Sedran T., Torrenti J-M and Hardy M., Formulation of optimized excavatable cement treated materials using a new punching test apparatus, *Mater Struct*, 51(3):56, 21 p, (2018). <https://doi.org/10.1617/s11527-018-1184-1>

[3] Morin C., Sedran T., De Larrard F., Dumontet H., Murgier S., Hardy M., Dano C. (2018) Development of an excavatability test for backfill materials: numerical and experimental studies, *Canadian Geotechnical Journal*, 55 (1), pp. 69-78, <https://doi.org/10.1139/cgj-2016-0534>

[4] <https://www.basiliskconcrete.com/en/>

[5] <http://amonit.fr/fr/accueil>

[6] <https://www.soletanche-bachy.com/fr/solutions/techniques/ground-improvement/biocalcis>

[7] Medevielle M., Gueguen-Minerbe M., Sedran T., Adaptation of alkalophilic bacterial strain, inducing CaCO₃ precipitation, to improve the recycled concrete aggregates quality | (Utilisation d'une souche bactérienne alcalino-résistante productrice de CaCO₃ pour l'amélioration de la qualité des granulats de béton recyclé), *Matériaux & Techniques*, EDP Sciences, 2016, 104 (5),506, doi : 10.1051/mattech/2017020.

[8] Heriberto Martinez Hernandez, Marielle Gueguen Minerbe, Yoan Pechaud and Thierry Sedran, Evaluation of the ability of alkalophilic bacteria to form a biofilm on the surface of Portland cement-based mortars, *Matériaux & Techniques*, 108 3 (2020) 304, Published online: 18 November 2020, DOI: 10.1051/mattech/2020032

[9] Kumar, J. P. P. J., Rajan Babu, B., Nandhagopal, G., Ragumaran, S., Ramakritinan, C. M., & Ravichandran, V. (2019). In vitro synthesis of bio-brick using locally isolated marine ureolytic bacteria, a comparison with natural calcareous rock. *Ecological Engineering*, 138, 97–105. <https://doi.org/10.1016/j.ecoleng.2019.07.017>

[10] Lambert, S. E., & Randall, D. G. (2019). Manufacturing bio-bricks using microbial induced calcium carbonate precipitation and human urine. *Water Research*, 160, 158–166. <https://doi.org/10.1016/j.watres.2019.05.069>

Thesis supervision

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Location of the thesis

The thesis will take place in the MAST/CPDM laboratory on the Marne La vallée campus (<https://cpdm.univ-gustave-eiffel.fr/>) for the first year for the microbiological aspects and in the MAST/MIT laboratory on the Nantes campus (<https://mit.univ-gustave-eiffel.fr/>) for the last two years for the mechanical characterization aspects of road materials.

