

Performance Evaluation of in Situ Application of Anhydrous Calcium Sulphate in Pavement Layers

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Abstract. The following paper concerns the in situ application of Anhydrous Calcium Sulphate (ACS) in Cement Bound Granular Material (CBGM) pavement layers. The ACS used in this research derives from an industrial process. If no applications are found for this industrial by-product, ACS is discharged into landfills. The research aims to evaluate the mechanical performances in real working conditions in which ACS partially replaces Portland Cement (PC). In the last years, the annual cement production worldwide is increasing rapidly reaching approximately 4.0 billion tons, responsible for around 8% of the total CO_2 emitted into the atmosphere. A trial four layers pavement, divided into two sections, was constructed and subjected to heavy traffic. Each section had the same type of layers except for the CBGM one. The first section was constructed using ACS in partial replacement of PC, while for comparison a reference section incorporated only PC was created. Each section was subjected to the same traffic flow and loads. To evaluate the performances of the two sections, tests were performed during the construction of the single layers. Also, after that the sections were completed, periodic tests were conducted. To perform the test a Falling Weight Deflectometer (FWD) was used, capable of measuring the pavement layers moduli. The results are encouraging, after six months from construction, the section incorporating ACS showed higher values of layer moduli if compared with the reference section. If the results are confirmed, the potential use of ACS in partial replacement of PC could decrease not only CO_2 emissions but also construction costs, with higher mechanical performance.

Keywords: Anhydrous Calcium Sulphate · Cement Bound Granular Material · Portland Cement · Industrial by-product · Circular economy

1 Introduction

The most common materials used in civil engineering are cement, steel, and sand. Each year, these three materials, are produced globally to supply the continuous demand to construct buildings and human-built environments [1]. Analyzing global 2020 annual productions of these materials, data from U.S. Geological Survey [2], cement production

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reached 4.1 billion tonnes, which accounted for 8% of global CO_2 emissions [3, 4]. Steel is the most commonly used metal, its production reached 1.8 billion tonnes, emitting around two tonnes of CO_2 for every tonne of steel produced. Sand and gravel production reached 265 million tonnes. As the world tries to reduce carbon emissions, by adopting various mythologies, it is important to study and evaluate new materials that can reduce the consumption of these essential materials. Cement is widely used in the road construction industry for many purposes like the construction of bridges, tunnels, and concrete roads. Also, it can be used for the treatment of aggregates as a hydraulic binder, and in the stabilization of soils, cement binding mixtures have a relevant contribution to upgrading the bearing capacity of the subgrade. In many parts of the world, researchers are studying alternative hydraulic binders to partially replace Portland Cement (PC). Normally such materials are by-products like fly ash [5], silica fume, and artificial gypsum [6–8].

The research investigates the potential application of Anhydrous Calcium Sulphate (ACS) in the partial replacement of PC as a binder in cement-treated base layers. Laboratory tests have already been conducted on the mechanical and physical behavior of ACS in partial replacement of PC in Cement Bound Granular Material (CBGM) layers with good results [5]. In this research, a mixed design incorporating 2% of PC and 5% of ACS in the CBGM layer is studied to evaluate mechanical performances, in real working conditions, while constructing a real scale trial road section.

ACS is a by-product obtained with lower temperatures than the calcination of PC that must reach 1400 °C [9, 10]. It is known that in the production of cement half of the CO_2 produced derives from the calcination of limestone [11] and the other half is produced using fossil fuels to heat the kilns. For this reason, all the potential applications of using ACS, that being by-product energy and CO_2 emissions for its production have already been spent, which could decrease the exploitation of natural resources, and limit energy consumption and CO_2 emissions.

2 Materials and Methods

The ACS used in this research is a by-product deriving from the industrial process to obtain Aluminum Fluoride and Cryolite that is used in the Aluminium industry. ACS has the chemical formula $CaSO_4$ and is also called milled anhydrite. It is obtained from the reaction of dried acid grade Fluorspar (CaF_2 97%) and Sulphuric Acid (H_2SO_4) during the production of Hydrogen Fluoride (HF) and consequent neutralization with lime [5], as shown in Eq. 1:

$$CaF_2 + H_2SO_4 \rightarrow 2HF + CaSO_4 \tag{1}$$

In Fig. 1 it can be seen an illustration of the industrial production process from which ACS derives.

The industrial plant that has supplied the ACS, is located on the island of Sardinia, Italy. The plant has an average annual production of 240000 t/year.

In this research CBGM layers, in which PC, type CEM IV/B 32.5 R, was partially replaced with ACS, are being studied to evaluate mechanical performances in real working conditions. In the summer of 2021, a trail embankment was constructed inside the

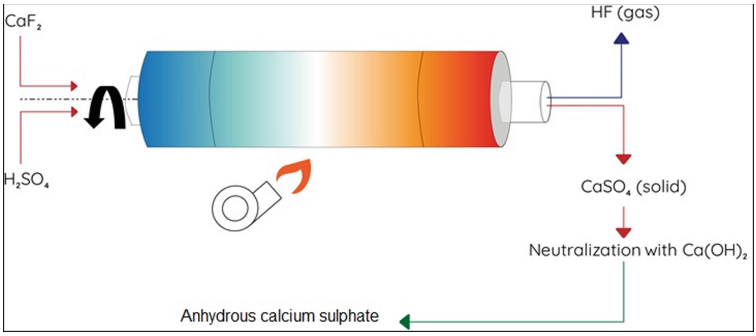

Fig. 1. Industrial production process of $CaSO_4$

industrial plant that supplied the ACS (see Fig. 2). It consists of two semi-rigid pavements with the same layers of thickness. The embankment was in total 90 m long and 6 m wide, formed of two sections that differ only on the composition of the CBGM layers. In Fig. 3 are shown the two test sections and the pavement layer thickness.



Fig. 2. Trial embankment inside the industrial plant

The section containing the innovative mix design, CBGM layer in green, has 5% ACS and 2% PC, while the section with traditional CBGM has only 3% PC used as a reference mix. Figure 4 is shown a typical layout of semi-rigid pavement, with materials normally used to prepare a CBGM mix, that is PC, water, and granular material. The trial section

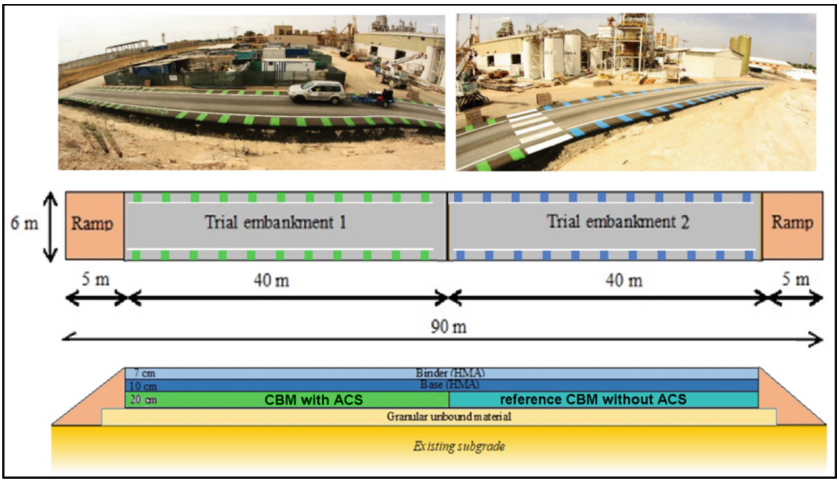

Fig. 3. The two trial pavements sections: in green pavement with ACS and in blue without.

was constructed on the pre-existing unbounded road, on top of that 20 cm of unbound granular material were laid to construct the foundation. On top of the foundation, the CBGM layer was constructed, with a thickness of 20 cm. The paving was then completed with two bituminous layers of Hot Mix Asphalt (HMA), respectively 10 and 7 cm thick, in total, the embankment was 57 cm high. Upgrading the bearing capacity of the hydraulically bound layers has a relevant contribution to the lower layers, this provides

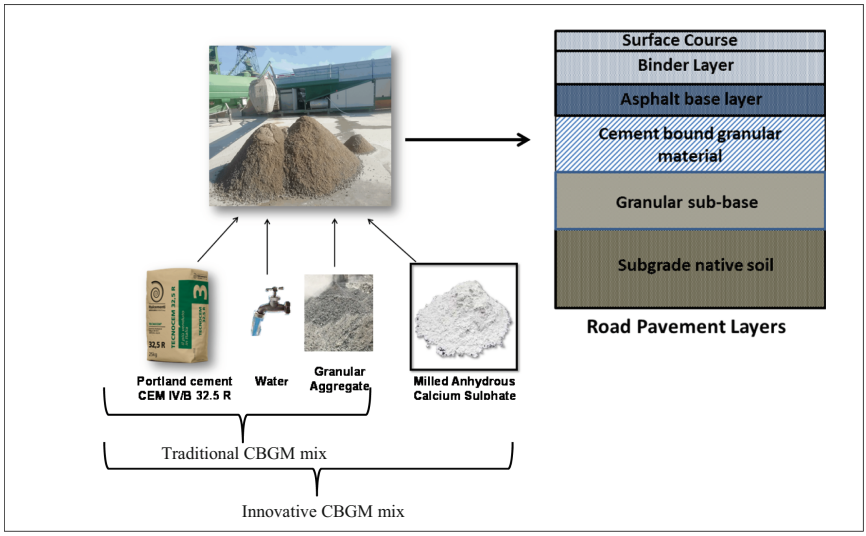

Fig. 4. CBGM mix components traditional and innovative; semi-rigid pavement layer layout.

the possibility to construct road surfaces (HMA) of lesser thickness with the result of decreasing road construction costs [12].

To evaluate the mechanical performances of the trial section a dynamic Falling Weight Deflectometer (FWD) was used (see Fig. 5). The FWD is a non-destructive testing device used to perform in situ tests on pavements. It is capable of measuring deflections obtained by applying an impulse with a falling load, the aim is to reproduce the vehicle wheel loads. The weight and the drop height of the falling mass can be modified: the weighting mass range is 50–350 kg, while the drop height is from 50–390 mm, so the impulse load can range from 40 to 120 kN acting on mass and drop height. Once the load stress is applied by control-shape dropping weight on a circular load plate, a line of 12 sensors (geophones) registers the vertical velocity at different distances from the load plate [13]. The main field of application of the FWD is in the monitoring of pavements: flexible (asphalt), rigid (concrete), and semi-rigid (asphalt and concrete). New applications are being tested like the application in rapid bridge conditioning [13–15].



Fig. 5. FWD on trailer towed by vehicle ready for testing on trial section

The amplitude and the shape of the basin, as shown in Fig. 6, contain information's about the stiffness of the layers of the pavement. While the time history of the deflection is useful to understand the dynamic properties of the underlying layers.

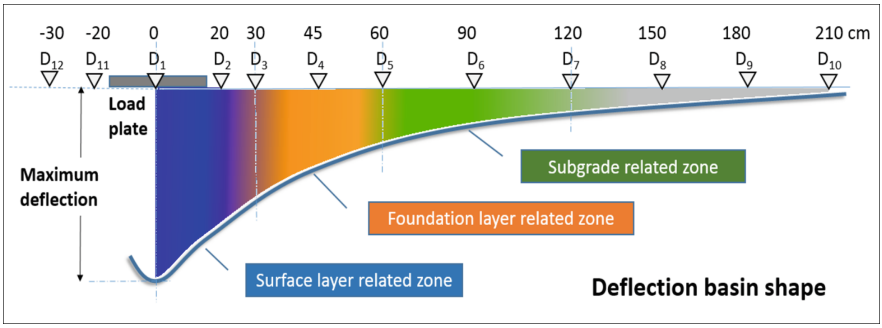

Fig. 6. Basin shape profile

3 Experimental Result

The testing campaign started in June 2021 and was repeated after 3 months, to evaluate the stiffness of the layers. Figure 7 reports the position of the testing points during the two testing campaigns (in June and September 2021).

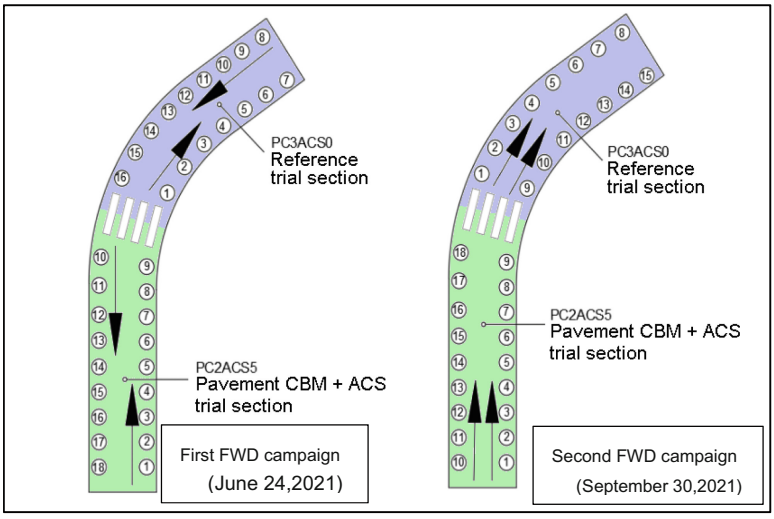

Fig. 7. Survey testing campaign layout

The grid to perform the tests used two alignments with a 4.0 m distance, while each station was 5.0 m distant from the next. On each tested point, the loading was repeated three times, each time increasing the load level 1000, 1300, and 1500 kPa. The impulse and that for deflections measured by the geophones were normalized in respect to the initial load and arranged on graphs showing the shape of the deflection basin. Figure 8, Fig. 9, and Fig. 10 are reported the mean deflection values of the two testing campaigns for each section, and for each applied contact pressure. It can be seen that the

innovative CBGM mix has always lower deflections than the reference mix for each of the three contact pressures applied. Also, it is possible to evaluate how both innovative and traditional CBGM layers have decreased the deflection values, comparing the campaign conducted in June with that of September.

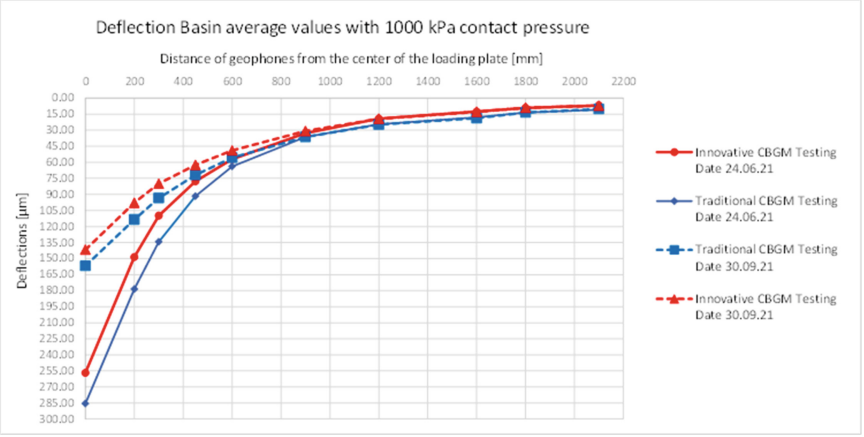

Fig. 8. Average deflection values with 1000 kPa contact pressure

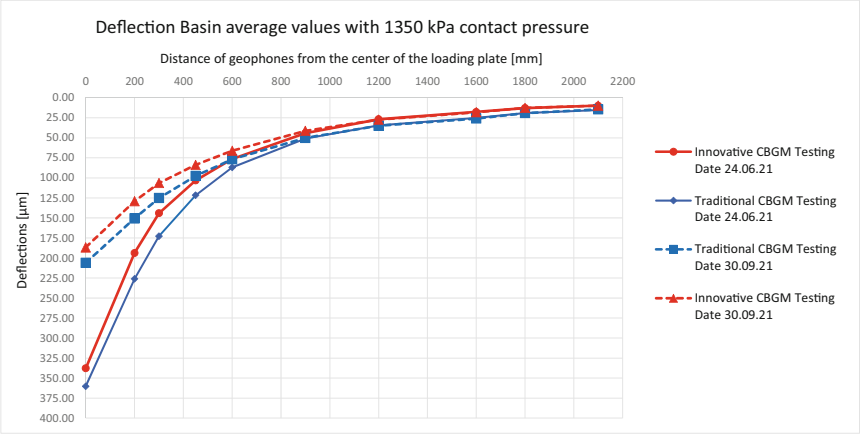

Fig. 9. Average deflection values with 1350 kPa contact pressure

To be able to obtain elastic moduli of the layers, from the data collected during the FWD campaign, back-calculation was performed using Elmod 6 software. In Fig. 11 are reported the mean elastic moduli values obtain performing back-calculation, for each of the layers of the campaign performed in June, and Fig. 12 the results for the tests performed in September. In particular, in the testing campaign performed in June 2021, the traditional mix had a value of elastic modulus 1398 MPa, while the innovative had

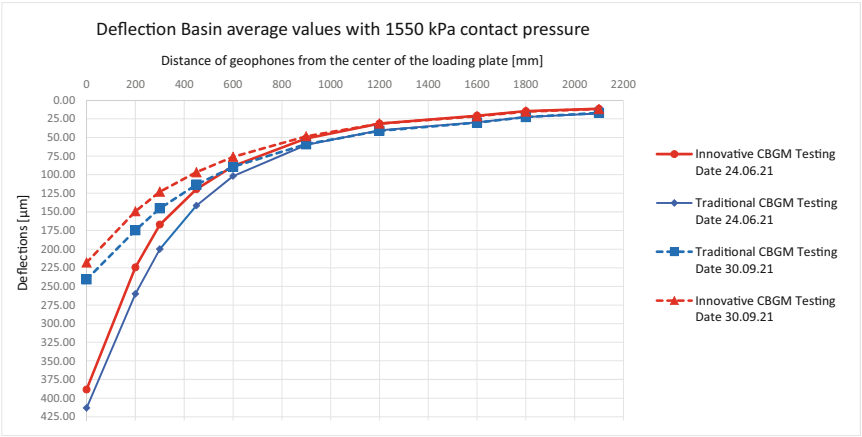

Fig. 10. Average deflection values with 1550 kPa contact pressure

a value of 1797 MPa. In the campaign conducted in September, the traditional mix had a value of 2818 MPa while the innovative mix had a value of 4082 MPa.

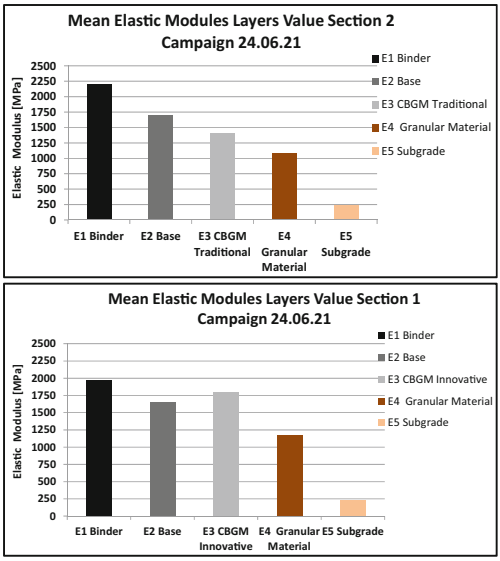

Fig. 11. Comparison of mean elastic moduli values of innovative and traditional CBGM Layers (Campaign 24.04.2021)

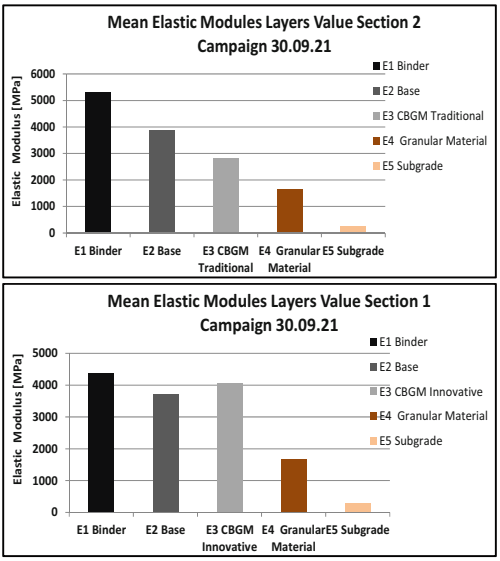

Fig. 12. Comparison of mean elastic moduli values for innovative and traditional CBGM layers (Campaign 30.09.2021)

4 Conclusions

The experimental campaign performed to evaluate the mechanical properties in real working conditions of CBGM layers incorporating ACS in partial replacement of PC, has demonstrated good mechanical performances. The in situ tests conducted using the FWD have highlighted an increase in stiffness for both the traditional and innovative cemented mix, as the curing times increase, with greater increases in stiffness of the section with the innovative mix design. The construction of the trial section has underlined some minor issues that can be simply solved, especially in the mixing and laying phases. Optimum water content in the mix must be strictly respected and the laying and compacting procedures must be done in a short period of time, in order to achieve good mechanical performances. ACS has a tendency to absorb more water than PC, making workability and compaction procedures difficult to perform.

The possibility of reducing the amount of PC in the mix, and introducing ACS, can be considered one way to decrease CO_2 emissions, but also construction costs.

The trial section will be periodically monitored, while it has been over a year since it has been constructed and subjected to heavy traffic. On the bases of the results obtained, new mixes will be tested, aiming for a further reduction of PC content, maintaining good mechanical performances, and also workability.

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