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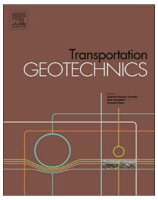

Long-term resilient and permanent deformation behaviour of Controlled Low-Strength Materials for pavement applications

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ABSTRACT

The paper deals with the long-term stiffness characterisation of Controlled Low-Strength Materials (CLSMs) for pavement applications in substitution of granular fill materials. Three alternative CLSM mixtures, two with ordinary Portland cement and a third one with an ultra-rapid sulpho-aluminate cement, were examined. Two different sample aspect ratios were considered and the samples were subjected to different testing conditions in terms of saturation, loading time and repetition. The investigated CLSMs are insensitive to variations of loading frequency and to water saturation, and sensitive to sample aspect ratio. They exhibit a significant increase in stiffness under repeated load triaxial testing and a low permanent strain accumulation. Finally, they exhibit an increase in resilient modulus when the deviatoric stress increases.

Introduction

Controlled Low-Strength Materials (CLSMs) are flowable mortars consisting mostly of cement, fine aggregate and water (Folliard et al., 2008; Alizadeh et al., 2014; Etxeberria et al., 2013). They often include admixtures to enhance both fluid and hardened properties, as well as secondary materials and by-products (e.g. fly ash, recycled materials, and alternative binders) to improve mixture properties and reduce the quantities of natural materials for lower production costs. Also known as flowable fill materials (FFM), CLSMs are employed in a variety of applications where the use of granular fill materials, or the excavated soils, do not provide the required performance and/or cause longer construction time and thus increased cost.

CLSMs can easily flow and fill irregular voids and trenches and they do not require compaction or vibration (i.e., they are self-levelling). They harden in a reasonably short time, reach mechanical properties similar or superior to those of soils, and maintain such properties over a long period of time while resisting adverse environmental effects and loadings. Such properties are greatly appreciated in road construction, maintenance works and pavement repairs.

A great variety of CLSMs with different short and long-term performance may be obtained by modifying the composition, proportion of components and mixing operations. To meet the required performance, the mechanical properties of CLSMs must be known and controlled during the design and construction stage. More specifically for pavement applications, CLSM should be

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excavatable when hardened and at the same time be resistant and stiff enough to bear and distribute the loads. In case of road applications (e.g. trench backfilling, bridge approaches, pavement repairs), the mechanical properties of CLSMs also need to be comparable to those of granular layers in order to assure a balanced distribution of stress and strains under the repeated traffic load.

Unlike soils and unbound granular material (UGM), CLSMs may show a gain in strength and stiffness due to curing that can have a significant implication for pavement applications (Folliard et al., 2008). For example, the gain in stiffness and strength during curing may gradually make the excavation (e.g. trench reopening) more difficult, resulting in an additional cost and labour. It is thus important that CLSMs have stable properties during their service life that are close to those of surrounding soils and UGM.

Strength and stiffness gain depends on the hydration phenomena and/or pozzolanic activity in those mixtures containing OPC or fly ash (Folliard et al., 2008; Bertola et al., 2013). In most CLSMs, fly ash is employed to partially substitute the cement in the mixture (Du et al., 2002), reducing thus mixture cost. It is also used to increase the flowability of mixtures thanks to its very fine dimension and spheroidal shape (Folliard et al., 2008; Du et al., 2002; Turkel, 2007). Similar effects and properties may be reached using functional admixtures with different proportions of the basic constituents. From the physical-volumetric point of view, CLSMs can be divided into two main families based on mix composition (Folliard et al., 2008): (a) mixtures containing fly ash and (b) mixtures without fly ash. The first group provides a highly flowable fresh mixture with a very low void content (lower than 3%). Group b, include admixtures (i.e., air-entraining agents) to produce a soft and flowable mixture with a high void content (15–30%) and low density.

CLSMs that do not contain fly ash seem to be more suitable to support road pavements in utility beddings and bridge approaches. The reason is that the use of the air-entraining agent leads to a lower density and higher air voids, improving insulation properties and frost resistance. Meanwhile, it contributes to a lower water/cement ratio and therefore decreases the segregation, bleeding phenomena, and related costs. Furthermore, a higher air void content hampers the long-term strength gain, thus assuring easy of future excavatability (Folliard et al., 2008).

For these specific applications, stiffness over time needs to be investigated in order to achieve comparable behaviour to those exhibited by soils and UGMs. In the case of repeated loading conditions, the most accepted stiffness parameter used to characterise base, subbase and subgrade materials is the resilient modulus (M_R). Referring to CLSMs, Folliard et al. (2008) advocate that future research on M_R is necessary to draw meaningful conclusions on the effects of mixture parameters on such fundamental material property.

This paper presents the results of an extensive laboratory investigation focused on the evaluation of long-term stiffness properties of CLSMs at various moisture conditions and stress levels. In particular, three different CLSMs suitable for pavement applications were investigated by means of the resilient modulus test according to AASHTO T307 (American Association of State Highway and Transportation Officials, 2007). The resilient modulus of CLSM can directly be used in structural analysis models to calculate the pavement response to wheel loads and to design pavement structures (American Association of State Highway and Transportation Officials, 2008).

Experimental study

This investigation focused on the characterisation of three CLSMs having various composition and properties. The ingredients used for these mixtures, as well as mixture compositions are presented next. The mix formulations followed recommendations based on past studies (Bertola et al., 2013). A primary focus in the present study was the assessment of the use of sulpho-aluminate cement (SAC) to replace the ordinary Portland cement (OPC) traditionally employed in producing flowable fill materials.

CLSMs made with SAC have been shown to have mechanical properties very similar to reference unbound granular materials normally employed in subbase and pavement repairs (i.e., trench backfilling, pavement rehabilitation). On the basis of such experience, the investigation focused primarily on two commercial formulations of CLSM with OPC and an alternative mix with SAC. Resilient modulus tests were carried out to characterise these CLSM mixtures, and to evaluate the effects of testing parameters and conditions on such materials. These mixtures do not contain fly ash or secondary recycled materials in order to control curing time effects. Tests were carried out after 90 days of curing in order to achieve the required mixture stiffness and to minimise stiffness variation at early stages due to the ongoing hydration process.

Materials

The materials used in the investigation included two cements: an ordinary Portland Type I/II cement (OPC) and a sulpho-aluminate cement (SAC), a natural sand with a gradation shown in Table 1, and an air-entraining agent in powder form with 0.85 g/cm^3 density.

The main characteristics of the cements are presented in Table 2. The OPC represents a typical cement used in CLSMs, while the SAC represents the alternative cement that has been shown to effectively reduce setting times and control strength and stiffness gain over time (Bertola et al., 2013).

Table 1
Sand sieve analysis.

Sieve	# mm	Passing %
#8	2.360	100.0
#16	1.180	99.9
#30	0.600	1.2
#50	0.300	0.2
#100	0.150	0.0
#200	0.074	0.0