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Skin friction coefficient change on cement grouts for micropiles due to sulfate attack

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HIGHLIGHTS

- Direct shear apparatus can be used to determine friction coefficient of cement pastes.
- Skin friction value for rough samples is bigger than for smooth ones.
- Coefficient of friction increases with time of immersion in sulfate solution.
- Sulfate attack do not have a negative effect on friction in conditions of this work.

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ABSTRACT

This paper presents a study of skin friction change of cement pastes used for micropiles as a geotechnical foundation when grout surface is affected by sulfate attack. In this research skin friction coefficient between cement paste – cement paste was measured, studying change in friction depending on the initial roughness of samples. Tests were performed after 3 and 6 months of immersion in a 15% Na_2SO_4 solution. Results show that sulfate attack increases skin friction coefficient for both surface finishes, concluding that this attack does not have a negative effect on friction in the experimental conditions of this work.

1. Introduction

A micropile is a small-diameter (less than 300 mm) cylinder-shape foundation which is drilled into the soil, usually grouted with cement pastes although mortars are also sometimes used, and reinforced with steel bars or pipes [1,2].

In geotechnical foundation, micropiles are commonly used to transfer loads from structures to deep strata when shallow soil is too soft to support those loads. These elements transfer their axial loads to bearing stratum through friction from grouts to surrounding soil as it is depicted in Fig. 1 [2].

The geotechnical capacity of micropiles depends on the amount of friction developed between soil and grout, being the interface surface roughness a critical factor in the shaft or bond capacity of a pile [3–5]. The surface roughness effect is more significant as the radius of the pile decreases [5,6], then this effect is even more important in micropiles than in piles as the radius of these elements is smaller than in piles. It is then expected that any change on cement paste skin properties, on the interface or on the soil surrounding the pile will affect the geotechnical capacity of the foundation [7].

It is well known that sulfate attack affects surface properties of concretes and other cementitious materials, precipitation of ettringite and gypsum on the surface, surface degradation and increasing surface roughness [8–11], therefore this change could affect to the interface between grouts and soil, varying skin friction coefficient and then micropile compressive capacity. Hence, it is of paramount importance to know if this change of surface properties would affect in a negative way the structural capacity of this type of foundation.

Skin friction coefficient is dependent on surface roughness of cement paste, and micropiles surface roughness highly depends on the type of soil being drilled. We can expect a smooth cement paste surface for a micropile drilled in a stiff clay, and a rough one when it is drilled, for example, in gravels [12]. In order to study this reliance on initial roughness, different surface finishes should be considered, since the change in friction coefficient due to sulfate attack could be affected by initial roughness.

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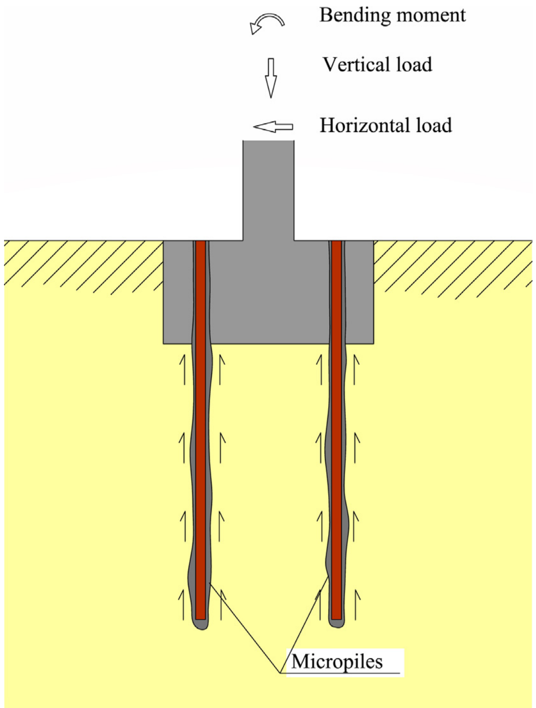

Fig. 1. Schematic representation of a micropile foundation where arrows represent the friction developed between cement grouts and soil [2].

There are two main factors, in the complex process of sulfate attack to cement paste, which could affect skin friction between cement paste and soil. These two factors are confining effect due to swelling, caused by reactions between cementitious materials and sulfates, and change in roughness of the grout surface caused by these reactions. Confining pressure due to swelling should have an increasing effect on skin friction, as friction force is directly proportional to normal forces, and this is the effect observed in previous works [13]. Nevertheless, the sense of change in skin friction due to sulfate attack on cement paste surface is not clear and it has not been studied before, being possible to change in a positive or negative way in the experimental conditions of this work.

It is then important to understand how skin friction coefficient change due to sulfate attack regardless other factors or processes. In order to do that, friction between cement paste – cement paste has been studied, avoiding to introduce other factors such as different behaviors and geotechnical parameters dependent on the type of soil or rock involved.

2. Materials and methods

2.1. Sample preparation

The cement pure samples were prepared using a commercial cement type CEM I 42.5 R, according to the Spanish / European standard UNE-EN 197-1 [14], with a water/cement ratio (w/c) of 0.50. Neither sand nor admixtures were used. This dosage of the grouts was chosen as it is between the limits of the Spanish guide for designing and building micropiles in road works [2], $0.40 \leq w/c \leq 0.55$. It is also lower than 0.55, as specifies the Spanish / European standard UNE-EN 14199 [15] and it is between 0.4 and 0.5 according to the Manual FHWA-SA-97-070 [1]. Moreover, a w/c ratio of 0.5 is normally used by the micropiles industry in Spain.

A typical circular shear box defined in the Standard [16] was used to determine the shear strength at the cement paste surface. This box is made from metal and divided in two halves, an upper and a lower half, which can move horizontally relative to each other. Hence, each sample was divided in two halves which will be placed into the shear box at the testing age. Cylindrical steel molds with accurate dimensions and flatness were made to prepare samples which will adjust into the shear box. In this case, cylindrical specimens of 60 mm diameter and 15 mm thickness were prepared. Due to surface roughness affects friction coefficient value, samples with two different surface finishes were prepared. A smooth surface was obtained by pouring the cement paste onto a smooth polypropylene plastic base, and a rough surface was obtained by pouring the cement paste onto a metal mesh, 2 mm aperture and 1 mm wire diameter, placed over the plastic base.

The control specimens were kept in a moist room and demolded after 24 h, when were submerged in distilled water, storing the container in a chamber at 20 °C for 28 days when the control specimens were tested. On the other hand, samples to test the friction coefficient evolution were as well demolded after 24 h, submerging the upper half in distilled water and the lower one in a 15% Na_2SO_4 solution in different containers, keeping all the containers in a chamber at 20 °C up to the testing time. Each sample consisted of two halves stored separately which will be placed into the shear box at the testing age. The upper half of these samples was kept in distilled water avoiding deterioration as this half had to be turned upside down at the moment of setting up the test and the damaged surface could have been affected by this process, for example falling out small pieces of samples. Furthermore, affecting only one surface of the samples simulates better field conditions where cement grouts are deteriorated by soils or water with sulfates but not the soil or rock in contact with grouts. Samples were submerged into the sulfate solution at such an early age to simulate field conditions where grouts are in contact with aggressive soils and water as soon as grouts are injected into the soil. As explained above, cement paste samples immersed in water have been used as reference samples so as to avoid the soils heterogeneity and to increase the reproducibility of the tests done. In this way, roughness of the reference samples is always the same. Moreover, as the goal of this research is to study skin friction coefficient change of surface cement pastes due to sulfate attack, soil samples could have introduced other effects [13] whose influence in the friction coefficient would have been difficult to be analyzed separately.

The volume of sulfate solution was approximately 4 times that of the samples volume according to the Standard ASTM C 1012-04 [17], being the solution completely renewed every 60 days.

To investigate the effects of sulfate solution on skin friction on the cement paste surface, tests were performed after 3 and 6 months of immersion in sulfate solution and after 28 days in distilled water for the control specimens.

2.2. Methods

The simple Coulomb failure criterion can be used to describe the ultimate shaft shear stress for cohesionless soils in piles [3,18]:

$$\tau = \sigma' \tan \varnothing \tag{1}$$

where τ is the shear stress developed on the grout surface, σ' is the normal effective stress and Ø is interface friction angle measured at peak shear stress. Same criterion is referred for micropiles where σ' is the grouting pressure [19]. In the present study, the Coulomb failure criteria is used to describe the relationship between normal and shear stress on cement paste surfaces.

Each sample consisted of two halves stored separately which will be placed into the shear box at the testing age. Once the two halves of the sample are set inside the box, a normal force is applied at the first stage of the test, applying afterwards a shear displacement rate to the upper half of the sample and measuring the shear force developed on the contact surface.

Three specimens were used per test, one per normal stress (100, 300 and 500 kPa) at each testing age, measuring shear stress developed at the samples contact until a peak value is clearly observed or the shear force tends to an asymptotic value. Although the repeatability of the shear test was not studied in the present work, the study of the coefficient of variation of previous works for different materials (soils, rocks and cement pastes) show good repeatability for direct shear test [20–22]. The choice of 500 kPa as the maximum normal stress is because it is a common value for the grouting pressure in micropile works, being also used as grouting pressure in previous works [6]. Three pairs of values (normal stress applied, maximum shear stress developed) are obtained from these tests at each age.

As the two halves of the sample were put together at the very moment of starting the test and filling the apparatus with distilled water, no cohesion is taken into account when evaluating the shearing resistance of the paste surfaces. Therefore, all shear strength is due to coefficient of friction, μ, that is related to the angle of skin friction Ø at the cement paste contact surface as follows $\mu = \tan$ Ø. This angle is the angle made between the applied normal stress and the maximum shear stress measured during the test. This relationship can be seen for a single sample in Fig. 2.

The three pairs of data (normal stress against the maximum shear stress), plus the origin of coordinates as no cohesion is taken into account, were plotted to determine the coefficient of friction of the grouts by drawing a line of fit for these data. The angle of this line with the horizontal axis represents the angle of skin friction and the slope of this line is equal to the value of the coefficient of friction.

As previously mentioned, the shear box was filled with distilled water to perform the tests according to the Spanish Standard UNE 103401 [16]. As the samples were kept into water or sulfate solution until the testing age, filling the shear box with water avoids contact surfaces getting dry during the test what could have affected the value of the coefficient of friction of the surface.