The Influence of Cement Content and Water to Cement Ratio on Capillary Absorption of Root-Pile Mortars

E. Laister, P.J.R. Albuquerque, G. Camarini, D. Carvalho

Abstract. For the design of mortar mixes for filling root piles, the Brazilian standard NBR 6122, establishes a minimum compressive strength of 20 MPa (28 days), minimum cement content of 600 kg/m^3 and a water to cement ratio between 0.5 and 0.6 and allows the use of water-reducing admixtures; however, the definition of a minimum cement content is a controversial topic about the guarantee of durability. Besides, cement content at these levels, will lead to axial compressive strength higher than 20 MPa, which is the minimum required by the standard, without much technological effort. The present study shows the influence of cement content and water to cement ratio on capillary absorption of mortars. It was found that, cement content, water to cement ratio and grain size distribution have an influence on capillary absorption. The study also demonstrates that it is possible to obtain mortars with low absorption for cement content lower than 600 kg/m^3 by controlling the overall grain size distribution and by adding chemical admixtures to control the amount of mixing water. However, for mortars where grain size control is not possible, such as mortars mixed on site, the minimum cement content of 600 kg/m^3 should be used to ensure low permeability.
Keywords: root piles, mortar, cement, durability.

1. Introduction

Root piles are widely used as a foundation in medium-to-large sized construction projects, mostly being the only alternative for the reinforcement of foundations of buildings and special structures. The pile is filled with a paste of cement or mortar, the latter being the most commonly used in Brazil. To obtain sufficient strength and durability, the Brazilian standard NBR 6122 (ABNT, 2010) specifies a minimum cement content of 600 kg/m^3 and water to cement ratio ranging between 0.5 and 0.6 for the production of mortar for filling the piles; superplasticizer admixtures, among others, may be employed to improve the performance of the mortar. The minimum cement content required by the NBR 6122 is high and has become a controversial topic in technical circles being heavily discussed as a result of trends in global sustainability and in terms of the cost of carrying out this type of foundation. Besides, such high cement contents will result in axial compressive strengths above the 20 MPa required by the standard.

From the durability point of view, cementitious materials can be deteriorated by action of external agents. For structures in contact with soil or buried, the most important deterioration agents are sulfates. Mortar is made of materials held together by a porous binder forming a complex of solids and pores (hydrated cement paste). The binder is the continuous phase in the composite and pores are critical with respect to movement of water and chemicals substances into or out of the mortar. This is a feature relevant to the durability of the mortar in service (Diamond, 2007). According to Dhir *et al.* (1994), durability tests are restricted to specialist laboratories; they take a long time to perform and are expensive. As durability is directly linked to the paste permeability for a defined cement, the lower the permeability the greater the durability.

Wassermann *et al.* (2009) highlight some of the reasons why the technical standards define minimum cement content for concrete. Firstly, this value goes back to a time when the water to cement ratio was controlled by means of cement content; secondly, there were few options in terms of water-reducing admixtures. Another important reason to have minimum cement content in the concrete or mortar is to guarantee a minimum amount of fines, ensuring workability and increased cohesion. Today, this is achieved by the addition of inert fines in order to increase the efficiency of the mortar without increasing cement content. These authors also evaluated the influence of cement content on the durability of concrete with cement content in the order of 230 to 450 kg/m^3 and w/c ratios varying between 0.45 and 0.70. They concluded that cement content is not a parameter that can be used to guarantee durability. With smaller values of cement content, there was a reduction in capillary absorption, which was caused by the refinement of the pores in the matrix due to the use of superplasticizer admixtures.

Neville (1997) emphasizes that in soils and groundwater, it is common to find sulfates of sodium, potassium, magnesium and calcium. These sulfates may originate naturally or they may come from industrial effluents or fertil-

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Submitted on December 9, 2013; Final Acceptance on July 18, 2014; Discussion open until December 31, 2014.

izers. The sources of sulfates, such as calcium sulfate, react with alumina compounds present in the cement paste, forming ettringite (hydrated calcium sulfoaluminate). As this reaction is expansive and occurs in the mature stages, when the material has already hardened, it can cause cracks in the paste with a consequent increase in permeability and loss of strength.

According to Mehta & Monteiro (2008), the best protection against attack from sulfate sources includes: low permeability, adequate cement content and low w/c ratio, good consolidation of the concrete, proper curing and, if possible, the use of a sulfate-resisting cement.

Schulze (1999) shows that the capillary absorption of mortar is a function of its w/c ratio and its cement content (Fig. 1).

In porous solids, water has an enormous impact on their degradation; the more impermeable they are, the more durable (Diamond, 2007). As this is the case with mortar, the capillary absorption test was chosen to provide indirect information in terms of mortar durability, mainly because this is a simple, low-cost and easy to perform test.

In the present work, a study of mortars prepared at construction sites and in laboratory, and industrial ones is presented. These mortars were evaluated by capillary absorption and axial compressive strength tests

2. Material and Methods

2.1. Mortars

Nine types of mortar were studied. Two were collected from construction sites that used root piles (Sites 1 and 2), four were industrialized mortars (named Grout 15, Grout 20, Grout 25 and Grout 30) and three were produced in the laboratory (Lab 336, Lab 475 and Lab 616). The mortars produced in the laboratory were prepared by adding filler to substitute part of the cement. Table 1 shows the composition of the studied mortars. These mortars were studied in fresh (consistency) and hardened state (compressive strength and capillary absorption).

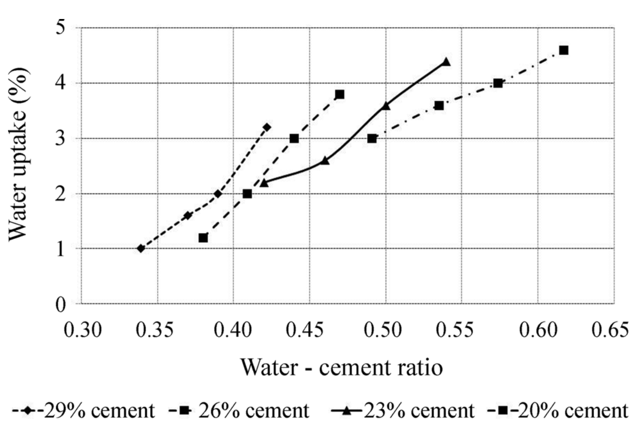

Figure 1 - Capillary absorption study conducted by Schulze (1999).

Table 1 - Characteristics of the mortars used in the study.

Mortar	Cement content (kg/m^3)	Filler (kg/m^3)	Aggregate - material passing through 0.15 mm sieve (%)	w/c	Water content (L/m^3)
Site 1	605	0	n/d	0.72	436
Site 2	636	0	n/d	0.82	522
Grout 15	242	n/d	23	1.09	264
Grout 20	286	n/d	19	0.92	263
Grout 25	330	n/d	21	0.80	264
Grout 30	374	n/d	25	0.71	266
Lab 336	336	336	19	0.80	269
Lab 475	475	204	20	0.57	271
Lab 616	616	68	20	0.44	271

Note: Mortars with minimum consistency of 90 mm by mini-slump test measured 30 min after mixing.
The mortars site1 and site 2 were made according to current regulations at the time of execution (1996). The setting of a range for the w/c was established in 2010 (NBR 6122/2010).

For all the mortars studied, 5 cm x 10 cm cylindrical specimens (diameter x height) were shaped manually according to the Brazilian standard NBR 7215 (ABNT, 1991).

Mortar curing was made as follows: the specimens from sites 1 and 2 remained at the site for the first 24 h; the specimens cast in laboratory were kept in moulds in a wet chamber for the first 24 h. After that, they were demolded and remained immersed in water until the time of the tests.

2.2. Consistency

The consistency of the mortar was measured using Kantro mini-slump (Kantro, 1980) (Figs. 2 and 3), which is a test used for fluid mortars. The test consists of measuring the diameter formed by the spreading of the fluid mortar over a glass dish after removing the mini-slump apparatus. The minimum value set as a reference for the mortars mixed in the laboratory and the grouts was a diameter of 90 mm measured 30 min after mixing, which is similar to the value obtained in mortars collected in the field (sites 1 and 2).

2.3. Compressive strength

Mortars compressive strength tests were made in four specimens for each age and for each mortar. The tests followed NBR 7215 (ABNT, 1991).

2.4. Capillary absorption test

The capillary absorption test was carried out at the age of 28 days in three specimens for each mortar. The tests followed NBR 9779 (ABNT, 1995). The specimens remained in the oven (105 ± 5 °C) until constant mass and were stored in a desiccator until they reached 23 ± 2 °C. The specimens were weighted and were subsequently placed over a grill in a container with water. The water level remained constant during the test at 5 ± 1 mm above the surface in contact with water.

The specimens were weighted after 3, 6, 24, 48 and 72 h. Before weighting, they were dried with a damp cloth to remove the excess water.

To ensure a unidirectional capillary absorption flow, a technique employed by the Laboratório de Aglomerantes e Resíduos (Laboratory of Binders and Wastes) at FEC/UNICAMP (Camarini *et al.*, 2011), was used. In this procedure, the lateral surface of the specimens are sealed with a latex-based waterproofing agent, thereby restricting the flow of water in just one direction, i.e. perpendicular to its axis.

The coefficient of capillary absorption was calculated using the Eq. 1.

$$C = \frac{A - B}{Area} \tag{1}$$

where C = absorption of water through capillarity (g/cm^2), A = mass of the specimen after immersion in the test receptacle in the respective period of time (g), B = mass of the specimen when dry in oven (105 ± 5 °C) until constant mass, as soon as it attains a temperature of 23 ± 2 °C (g), in the desiccator and $Area$ = cross-sectional area of specimen (cm^2).

3. Results and Discussions

3.1. Consistency

Table 1 shows the quantity of water needed to obtain the consistency required for the mortar pumping. A diameter of 90 mm measured by the mini-slump test was required 30 min after mixing. If the water to cement ratios (between 0.5 and 0.6) proposed by NBR6122 (ABNT, 2010) were used for these water contents, it would be obtained:

- For mortars collected from the construction sites, a water to cement ratio of 0.5 and water content between 436 and 522 L/m^3, leading to cement contents of 872 kg/m^3 and 1044 kg/m^3, respectively; for mortars with a water to ce-

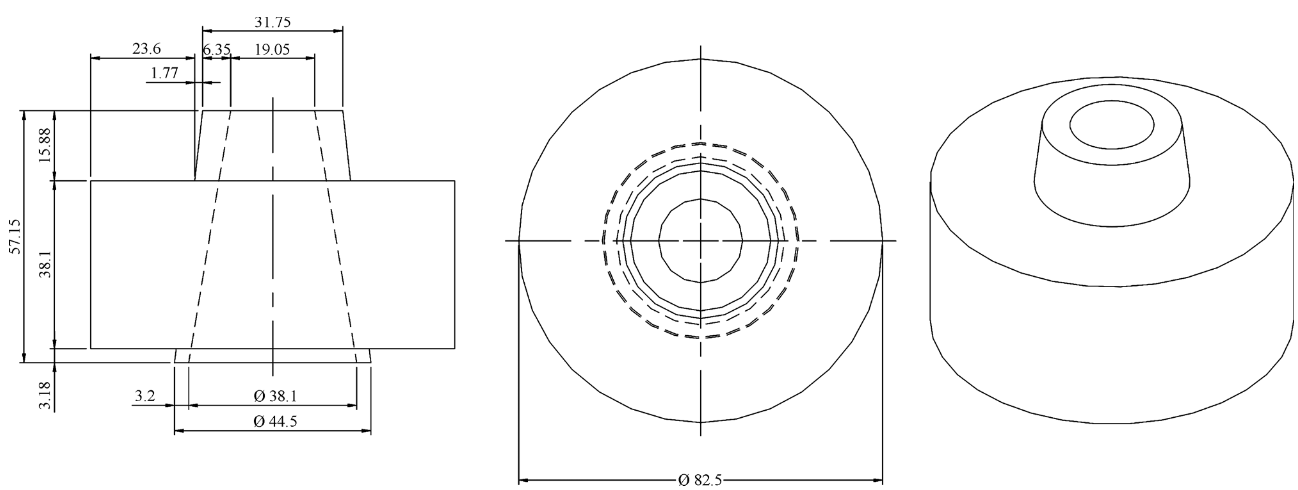

Figure 2 - Project design of mini-slump apparatus (units in mm) (Based on Kantro, 1980).

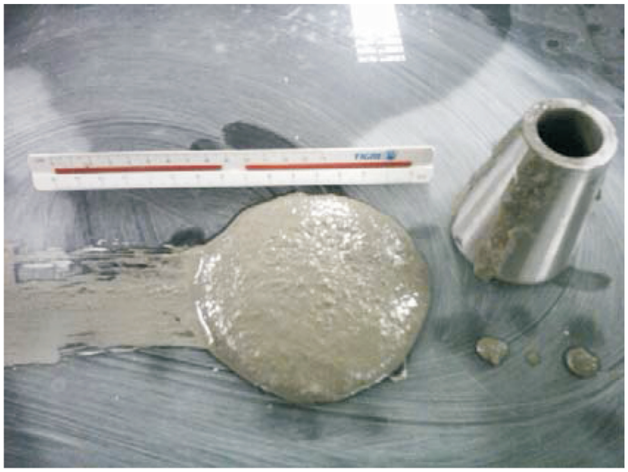

Figure 3 - Mini-slump test (Laister, 2012).

ment ratio 0.6 and water content between 436 and 522 L/m^3, the cement content would be 726 kg/m^3 and 870 kg/m^3;

- For laboratory (Lab) and industrial mortars (Grout), a water to cement ratio of 0.5 and water content ranging from 263 to 271 L/m^3, result in a cement content of 526 kg/m^3 to 542 kg/m^3. These same mortars with a w/c of 0.6 result in a cement content of 438 kg/m^3 to 451 kg/m^3.

These results indicate that to maintain the w/c ratio and the fluidity with cement content of 600 kg/m^3 it is necessary to use a water-reducing admixture.

In laboratory conditions it was not possible to mix mortars with a cement content lower than 600 kg/m^3 using superplasticizer admixture without segregation. However, it was possible to mix mortar with a cement content lower than 600 kg/m^3 by replacing a part of the cement with limestone filler.

3.2. Compressive strength

Figure 4 displays the axial compressive strength obtained for the different types of mortar. Dotted line is the minimum value established by the Brazilian standard.

The mortars designated as Grout 15 (242 kg cement/m^3) and Lab 336 (336 kg cement/m^3) had strength under 20 MPa. On the other hand, the mortars Grout 20 (286 kg cement/m^3), Grout 30 (374 kg cement/m^3) and Lab 475 (475 kg cement/m^3), had strength above 20 MPa, with a cement content lower than 600 kg/m^3. The results also showed that the mortar Lab 475, which was the one with the lowest cement content, attained a compressive strength 20 MPa.

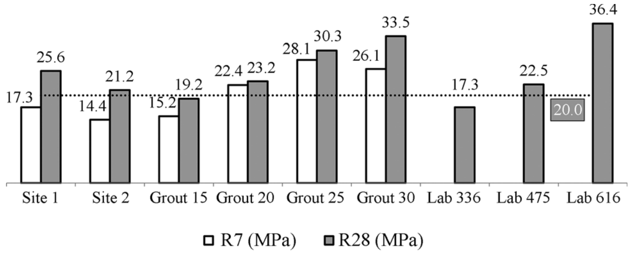

Figure 4 - Axial compressive strengths of the mortars studied (Laister, 2012).

2.3. Capillary absorption

Figure 5 shows the capillary absorption of the studied mortars.

The Site 2 mortar was adopted as reference of capillary absorption test (absorption limit), because it was collected in the field, was prepared according to the prevailing standards and by an experienced company.

From the capillary absorption results (Fig. 5), it can be seen that Grout 15 and the mortars Lab 336 and 474 showed capillary absorption above that of the mortar used in Site 2 (reference). They are not therefore efficient in terms of capillary absorption. The Lab 616 mortar was the only one mixed in the laboratory which met the reference, both in terms of strength and capillary absorption (absorption below the reference value). It was not possible to obtain mortars mixed in the laboratory with capillary absorption less than or equal to the reference mortar using a cement content of less than 600 kg/m^3 (Site 2).

Grout 20 had a capillary absorption similar to that of Site 2 (reference), while Grouts 25 and 30 displayed capillary absorption lower than that of the mortar on Site 2 (reference). Grouts 25 and 30 were generally more effective because, with their smaller cement content, they had lower capillary absorption (Fig. 5).

Grout 30 had the second lowest capillary absorption (Fig. 5). This sample contains the highest quantity of total fines (Table 1), which may have contributed to a better particle packing density, producing a smaller quantity of capillary pores or even interrupting the interconnecting capillary pores.

Table 2 sumarizes the compressive strength and capillary absorption of the studied mortars.

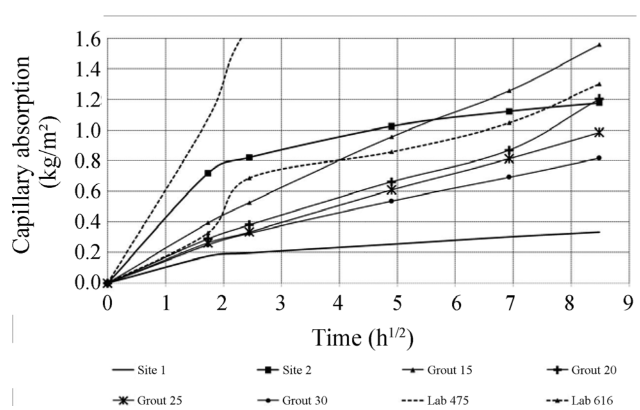

Figure 5 - Capillary absorption of the mortars studied (Laister, 2012).

Table 2 - Compressive strength and capillary absorption of mortars. Site 2 mortar was taken as reference.

Mortar	Compressive strength fc ≥ 20 MPa*	Capillary absorption**
Site 1	Yes	-
Grout 15	No	No
Grout 20	Yes	Yes
Grout 25	Yes	Yes
Grout 30	Yes	Yes
Lab 336	Yes	No
Lab 475	Yes	No
Lab 616	Yes	Yes

fc = axial compressive strength.
*"Yes" - mortars with compressive strength ≥ 20 MPa (reference). "No" - mortars with compressive strength < 20 MPa.
**"Yes" - mortars with capillary absorption ≤ site 2. "No" - mortars with capillary absorption > site 2.

These results show that industrial mortars can have an excellent performance in terms of compressive strength and capillary absorption, demonstrating that is possible to use them for root piles. With industrial mortar it is possible to have a more appropriate technological control. Mortars produced on site must have a high cement content to guarantee the desired absorption.

4. Conclusions

The present study found that the quantity of fines in the cement matrix helps to ensure that segregation does not occur. Therefore, for mortars where grain-size control is not possible, such as those mixed on construction sites, a minimum cement content of 600 kg/m^3 should be used, in order to guarantee low mortar permeability. To obtain fluid mortar and to maintain the w/c between 0.5 and 0.6, a water-reducing admixture should be used.

The study also showed that the grouts were the products with lowest capillary absorption, even though they had the lowest cement content. These formulations contain a higher quantity of fines than conventional mortar, contributing to a better overall grain-size distribution, making possible to work with cement content lower than 600 kg/m^3 without negative impacts on permeability. In other words, it is possible to work with smaller cement content if adequate technological procedures are adopted.

In the case of construction sites where it is not possible to perform a grain size control of the mixture, neither the use chemical admixtures, the addition of filler and a cement content of a least 600 kg/m^3 are good measures to ensure low permeability and to increase robustness in the whole manufacture process. A cement content of 600 kg/m^3 leads to a lower w/c ratio and provides a quantity of fines so that segregation does not occur.

The setting of a range for the w/c ratio could promote a significant increase in the content of cement. Depending on the high fluidity and the characteristics of the inputs available at the construction site it could possibly demand more water. Therefore, it is also necessary to define the range of consistency for pumping and also the capillary absorption performance, which could promote more economical, more durable mortars, making the content of cement more flexible maintaining the performance, both in its fresh state (avoiding segregation) and also in the hardened state (minimum compressive strength and limiting capillary absorption).

References

ABNT NBR 6122 (2010) Projeto e Execução de Fundações. Associação Brasileira de Normas Técnicas, Rio de Janeiro, Brasil, 91 p.

ABNT NBR 7215 (1996) Cimento Portland - Determinação da Resistência à Compressão. Associação Brasileira de Normas Técnicas, Rio de Janeiro, Brasil, 8 p.

ABNT NBR 9779 (2012) Argamassa e Concreto Endurecidos - Determinação da Absorção de Água por Capilaridade. Associação Brasileira de Normas Técnicas, Rio de Janeiro, Brasil, 3 p.

Camarini, G.; Pereira, V.M.; Freitas, P.M.G. & Tirello, R.A. (2011) Methods to measure the transfer properties of mortars. Applied Mechanics and Materials, v. 148:149, p. 184-187.

Dhir, R.K.; Jones, M.R.; Byars, E.A. & Shaaban, I.G. (1994) Predicting concrete durability from its absorption. Durability of concrete. Third International Conference, Malhotra, Nice, ACI - SP – 145:62, p. 1177-1194.

Diamond, S. (2007) Physical and chemical characteristics of cement composites, In: Page, C.L. & Page, M.M. (eds) Durability of Concrete and Cement Composites. Woodhead Publishing and Maney Publishing, CRC Press, p. 10-44.

Kantro, D.L. (1980) Influence of water-reducing admixtures on properties of cement paste - A mini slump test.

Cement and concrete aggregates. Winter, v. 2:2, p. 95-102.

Laister, E. (2012) Influência do Consumo de Cimento e da Relação Água/Cimento em Argamassas para Execução de Estaca Raiz. Dissertação de Mestrado, FEC, Unicamp, 160 p.

Mehta, P.K. & Monteiro, P.J.M. (2008) Concreto, Microestrutura, Propriedades e Materiais. Ibracon, São Paulo, 674 p.

Neville, A.M. (1997) Propriedades do Concreto. PINI, São Paulo, 828 p.

Schulze, J. (1999). Influence of water-cement ratio and cement content on the properties of polymer-modified mortars. Cement and Concrete Research, v. 29:6, p. 909-915.

Wassermann, A.; Katz, A. & Bentur, A. (2009) Minimum cement content requirements: A must or a myth? Materials and Structures, v. 42:7, p. 973-982.