Influence of chip-size on development of adhesion for conditioned clayey soils

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Influence of chip-size on development of adhesion for conditioned clayey soils

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ABSTRACT: In the excavation of clayey soil with Earth Pressure Balance TBMs, the study of soil conditioning is a complex issue. The presence of a mix of water, clay and foam, often added with polymers, makes the resultant mass a material strongly time-dependent and where the internal forces are given both by mass and surface actions. Differently from granular soils, where the time-dependence of the conditioned mass is ruled by the decay of foam, in clays one the rate of adsorption of the liquid phase of the conditioning into the clay chips cannot be neglected since strongly affects the quality of the conditioned mass in time. This paper compares the difference in the adsorption rate through the evaluation of the dynamic adhesion for different chip size. For each studied clay, different chip size distributions are obtained and tested. The difference in the development of adhesion reflects the different rate of adsorption of the liquid phase showing that the dimensions of the chips should be considered in the choice of clay conditioning parameters with reference also to the estimated time spent by the conditioned material to go through the excavation chamber and to exit from the screw conveyor.

1 INTRODUCTION

In the industry of tunneling, a large share of the market is occupied by Tunnel Boring Machines (TBMs) excavations. Among this share, Earth Pressure Balance (EPB) are frequently used. EPB-TMB rely their functioning on the correct assessment of soil conditioning. This means that the right dosage of conditioners, usually water and foam, must be added to soil to change its behaviour. In particular a high flowability, a low permeability, a low wear potential and high compressibility are desirable.

The process needed to assess of the right dosage of conditioners has been studied by several authors (Vinai et al. 2008, Thewes & Budach 2010, Martinelli et al. 2015, Mooney et al. 2017, Peila et al. 2019, Carigi et al. 2020a) for cohesionless soils.

In the case of cohesive soils, one additional feature has to be controlled. For clay conditioning is of paramount importance to correctly assess how to avoid clogging. With this scope several researches were developed by Hollmann & Thewes (2013), Thewes & Hollmann (2016), Khabbazi et al. (2017) that highlighted a strong relationship between the water content, together with the Atterberg's limits, and the clogging potential.

Unlike from what happens in cohesionless soils where, being the grains inert, the decay of the efficacy of soil conditioning depends only on foam degradation rate and water evaporation (Carigi et al. 2020b), in clay it plays a determinant role also in the progressive hydration of the chips detached from the excavation face (Galli & Thewes, 2014), as depicted in Figure 1.

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The clay chip and clumps, which usually have dimensions up to decimeters, progressively adsorb water from the surrounding environment modifying their behaviour accordingly. This change is progressive and does not reach its conclusion before the material is extracted and discharged on the belt conveyor. This means that in ordinary TBM drive conditions is inevitable to deal with an evolutive material.

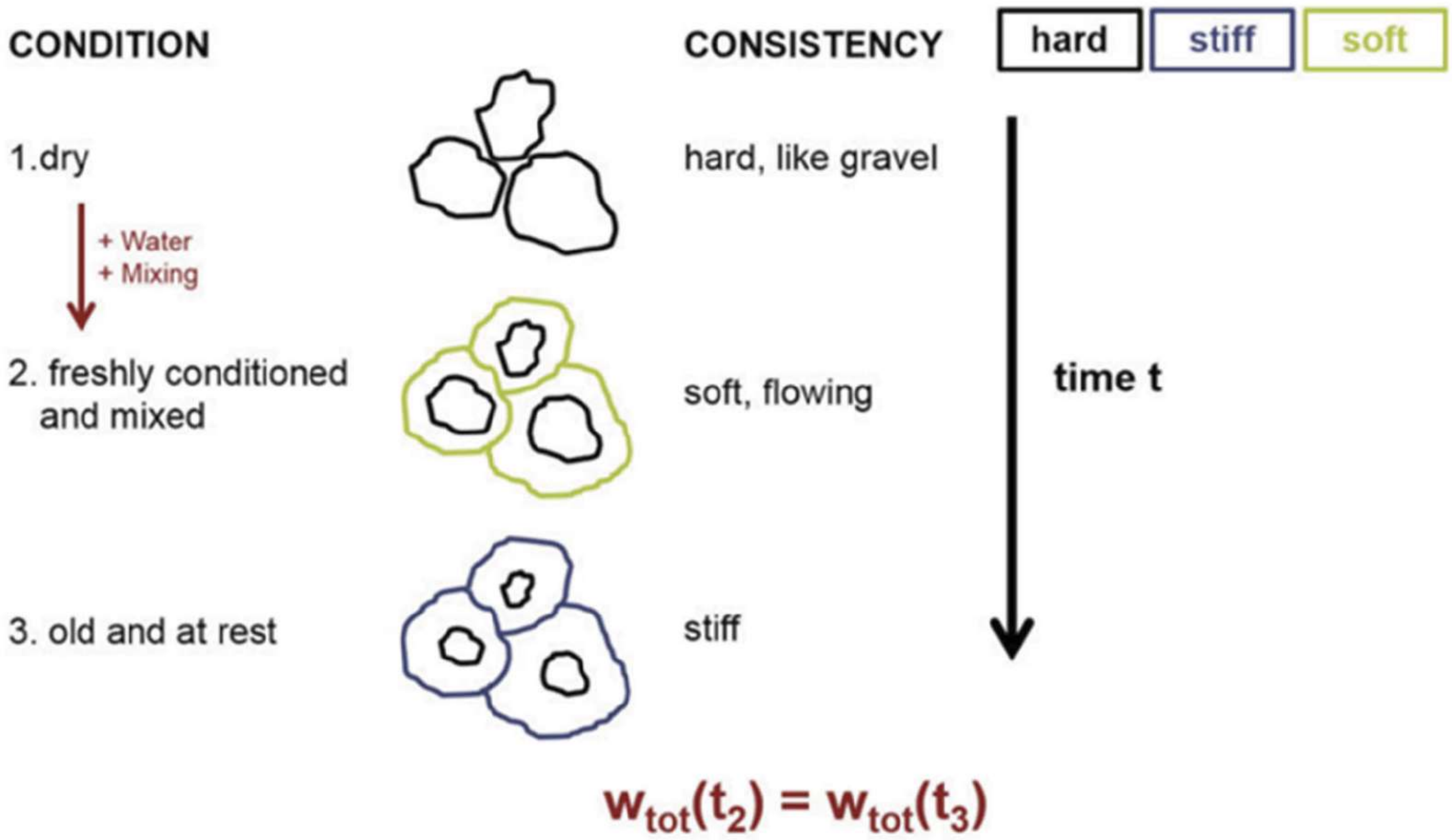

Figure 1. Phenomenological scheme or the conditioned clay behavior, from Galli & Thewes (2014).

In scientific literature several authors focused on the behaviour of powder of clay or, anyway, on highly homogenized clay through a Hobart mixer (Sebastiani et al. 2017. De Oliveira et al. 2018).

Todaro et al. (2022) introduced a procedure that performs evaluations also on clay chips. In particular, the Dynamic Adhesion Test highlights the strong time dependence of the behaviour of conditioned clay, but no assessment about the influence of the dimensions of the chips was made.

In this paper, the same test is applied to 3 samples of the same clay but with different chip size distributions conditioned in the same way to highlight the importance of the chip dimension in the assessment of clay conditioning.

2 MATERIALS AND METHOD

2.1 *Clay*

The natural water content has been determined accordingly to ASTM D2216-92 and its Atterberg limits accordingly to ASTM D4318-17. The density of the chips has been determined according to ASTM D7263-21. The results are given in Table 1.

Using the classification proposed by Hollmann & Thewes (2013), the clay is in a hard state as shown in Figure 2.

Using the clay available, 3 samples with different chip size distributions have been created and named “Coarse”, “Medium”, and “Fine”. The chip size distributions are given in Figure 3 while a picture of each sample is given in Figure 4 (the background mesh has a size of 1 cm).

2.2 *Conditioning*

The conditioning has been performed using a commercial conditioning agent based on sodium laureth sulfate, and the foam has been produced with the foam generator described by Vinai et al. (2008).

Table 1. Clay properties.

Density	γ (g/cm^3)	1.74
Water content	w_n (%)	6.0
Liquid Limit	LL (%)	44.0
Plastic Limit	PL (%)	22.0
Plastic Index	PI (%)	22.0
Consistency index	CI (%)	1.73

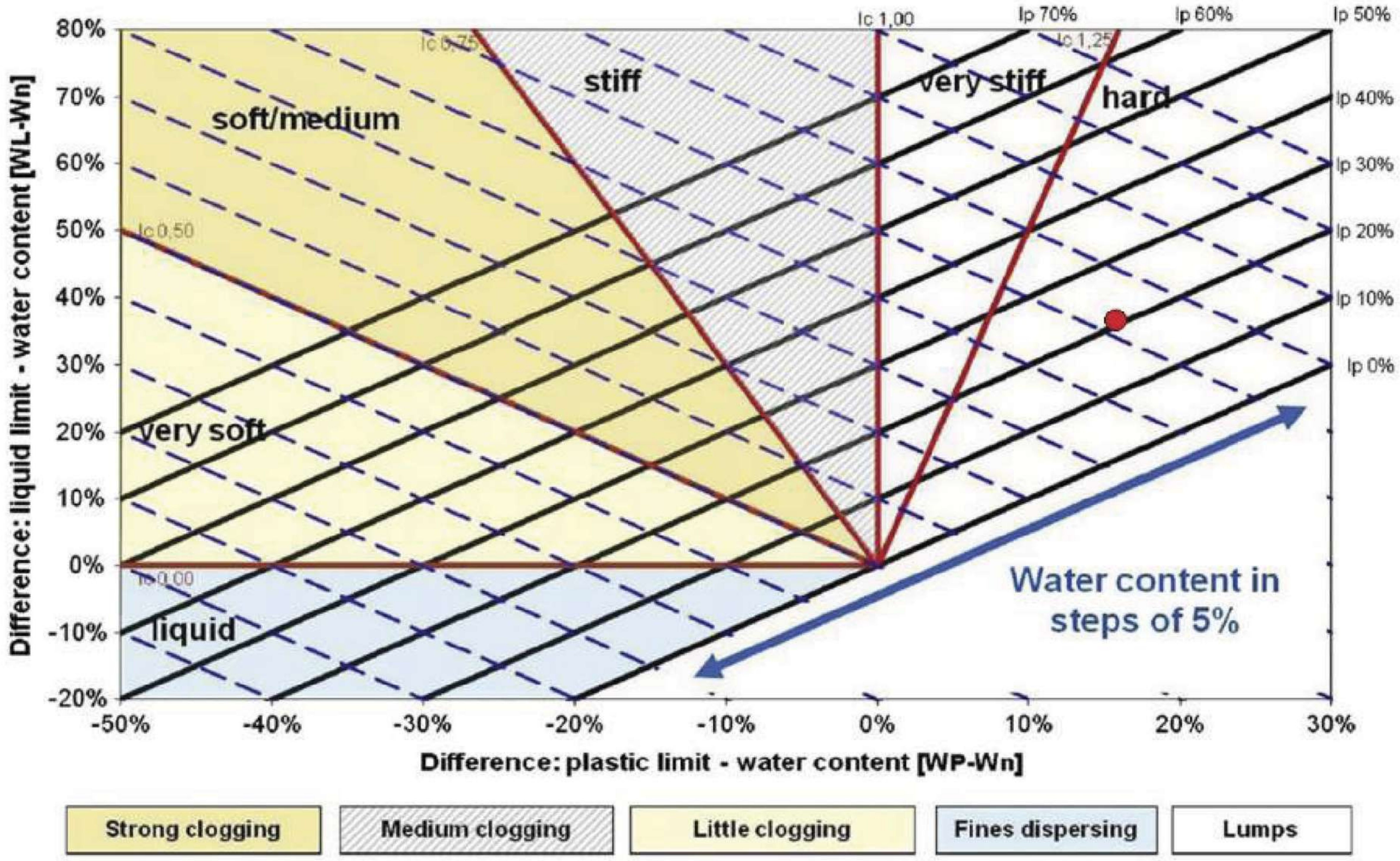

Figure 2. Clay classification accordingly to Hollmann & Thewes (2013).

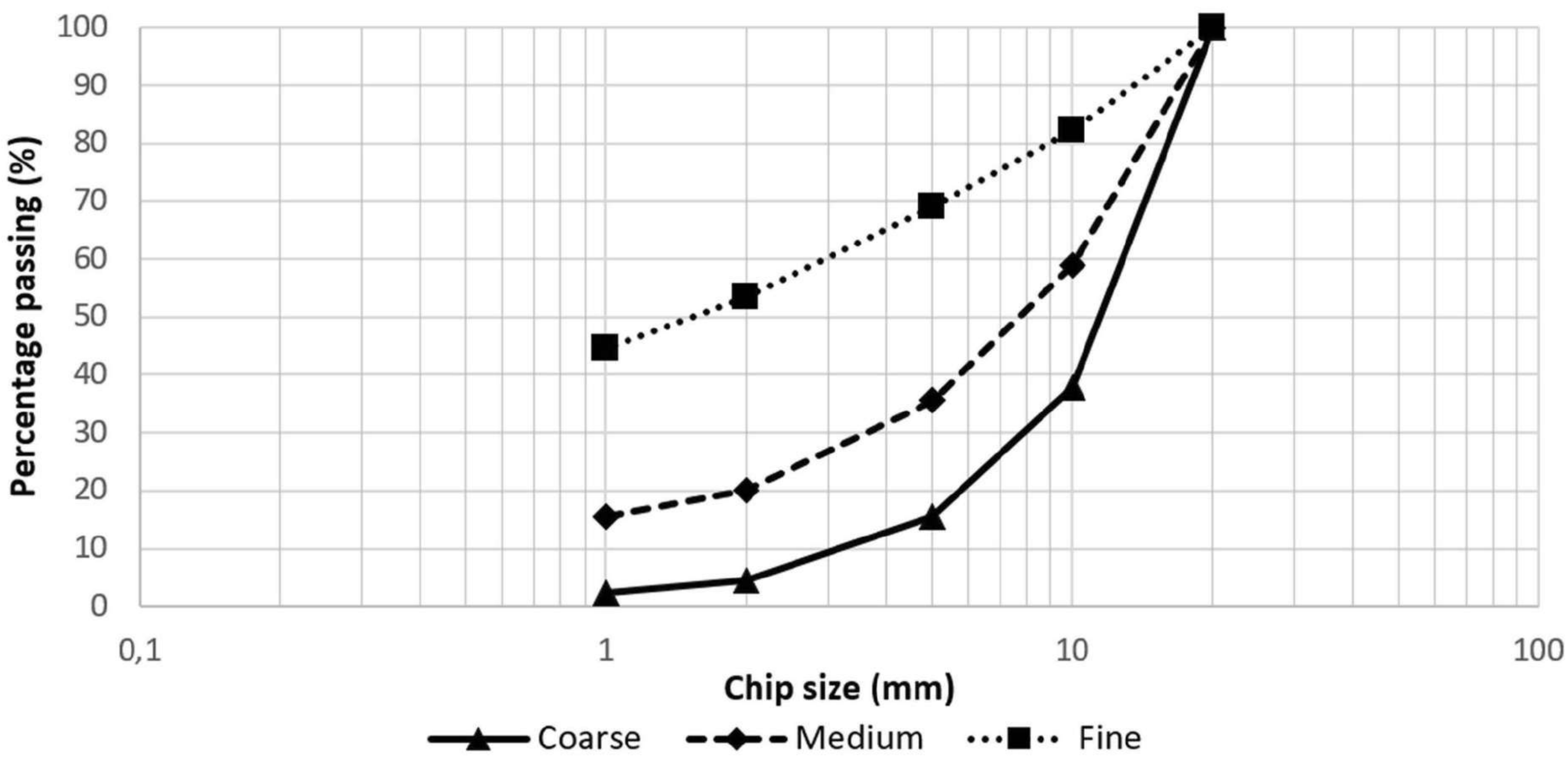

Figure 3. Chip size distributions of the 3 samples.

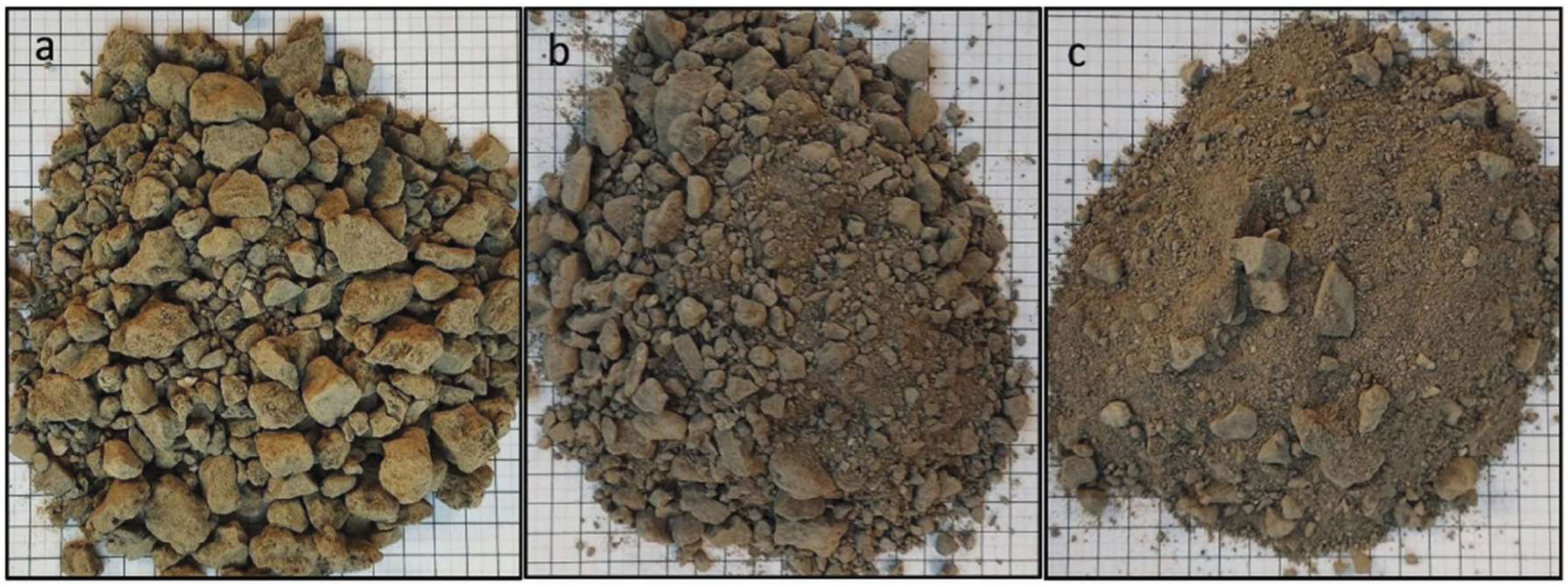

Figure 4. Pictures of the samples: a – Coarse; b – Medium; c – Fine.

According to Todaro et al. (2022), the soil is mixed with added water and foam for 2 minutes.

In order to highlight the effect of the chip size distribution on the result of the test, the same conditioning parameters have been used for each sample. These parameters are given in Table 2.

Table 2. Conditioning parameters.

Added water	w_{add} (%)	30
Liquid generator concentration	c_f (%)	1.5
Foam Expansion Ratio	FER (-)	8
Foam Injection Ratio	FIR (%)	50

Taking into account also the liquid added through foam, the overall water content is obtained as stated in Equation 1:

$$w_{tot} = w_n + w_{add} + \left(\left(V_{sample} \cdot FIR\right)/FER\right) = 38\% \tag{1}$$

In Figure 5 is given the new position of the soil on the Hollman & Thewes (2013) diagram obtained with the water content of Equation 1, with respect to the previous position and the theoretical path between the initial and final states.

Figure 5 Clearly shows that the material should have a hard consistency before conditioning and a very soft consistency after, while no clogging is forecasted in the former condition and little clogging in the latter condition.

No information is given about the transition between these two states.

2.3 *Test methodology*

The conditioned soils have been tested according to the procedure described by Peila et al. (2016).

In this test, a metallic disk of 120 mm diameter spins inside the conditioned material at 90 rpm for 300 s. The conditioned material is placed in a tank in 320 mm of diameter and, through a metallic plate equipped with hydraulic jacks, is kept at the pressure of 0.1 MPa. During the test, the torque required to spin the metallic disk at constant speed is measured.

Between the completion of the conditioning process and the beginning of the test, 5 minutes lapsed due to the required setup time of the test.

A picture of the test setup is given in Figure 6.

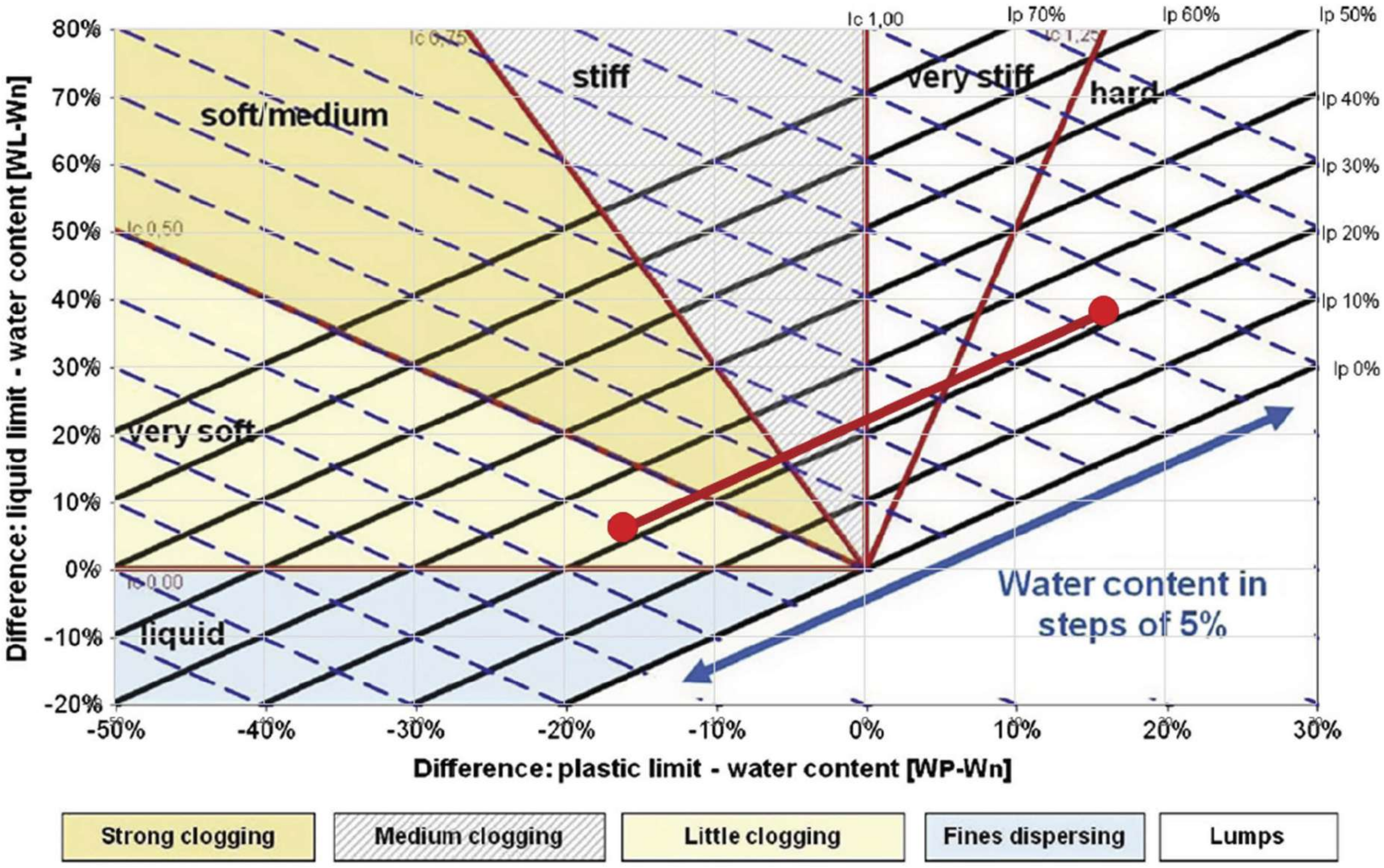

Figure 5. Theoretical path on Hollmann & Thewes' (2013) diagram.

From simple geometric considerations, it is possible to state that the measured torque and the average tangential adhesion on the disk are directly proportional as given in Equation 2.

$$T = \tau \cdot 2A \cdot \frac{2}{3} R \tag{2}$$

where T = torque; τ = average tangential adhesion; $2A$ = total area of the disk (upper and lower sides); and $2/3R$ =lever arm.

Hence, all the following considerations on the torque are equally valid for the average tangential adhesion.

3 RESULTS

In Figure 7 the results of the test on the 3 materials are presented.

As shown in Figure 7, the torque and the adhesion develop continuously during the test.

For the coarse chip size, the development is very slow within the 300 s of test and reaches modest values. For medium chip size, the development of adhesion is maximized while fine chip size develops an adhesion that falls between the two other results.

This result can be explained considering the increasing specific surface as the chip size decreases. In fact, as the specific surface increases, the amount of water adsorbed by the chips in the considered time, from the conditioning to the end of the test, increases as well, leading to the following situations.

The coarse material is composed of chips internally non-conditioned in a very fluid mud. The mud shows a very low viscosity, and the chips, being in a solid state, contribute to the increase of torque mainly in an attritive way.

The fine material adsorbs well all the conditioning agents, leading to a fairly homogeneous material that shows little clogging as expected using the diagram of Hollmann & Thewes (2013).

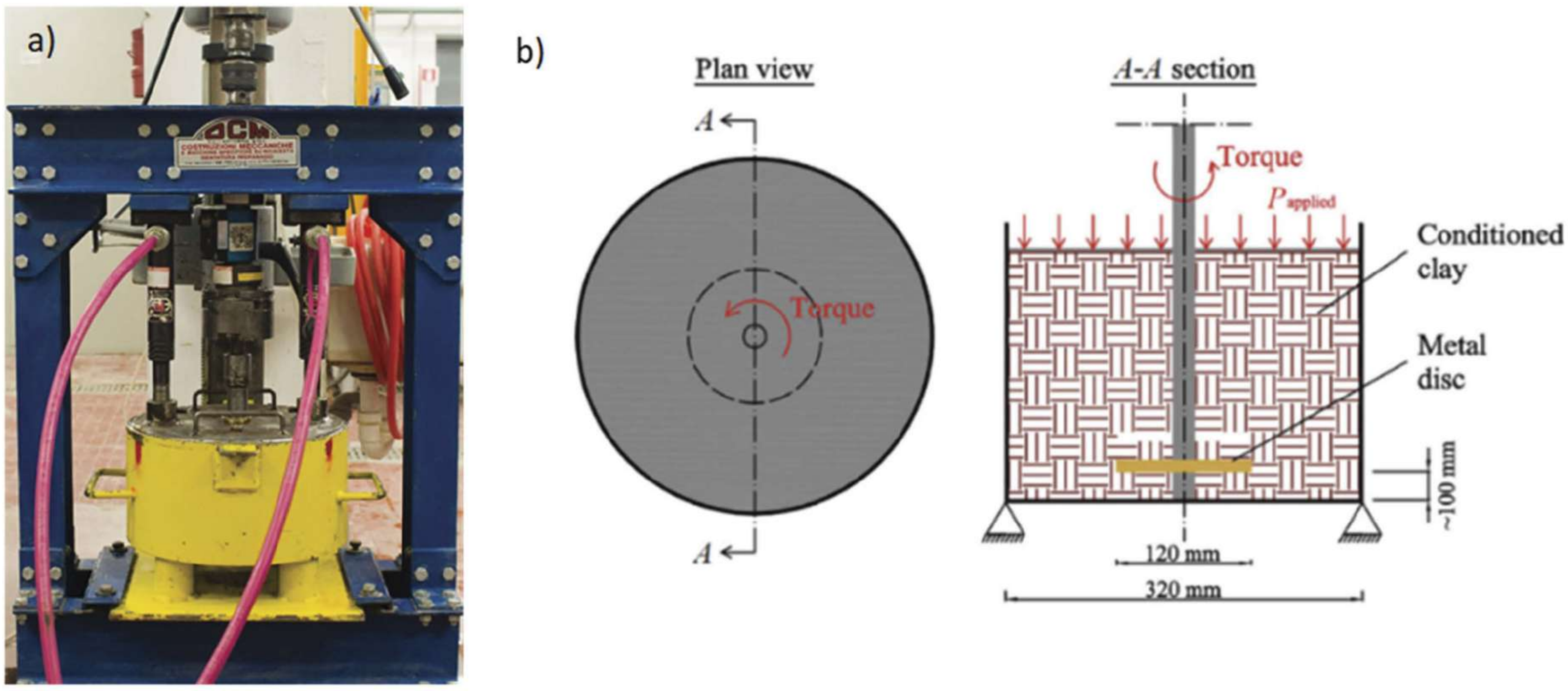

Figure 6. Dynamic adhesion test setup.

The medium material adsorbs the conditioning agents less efficiently than the fine material due to the reduced specific surface and, during the test, falling somewhere between the two conditions shown in Figure 4 on the strong clogging zone.

Those tests highlight how the difference in grain size distribution cannot be neglected in evaluating clogging risk.

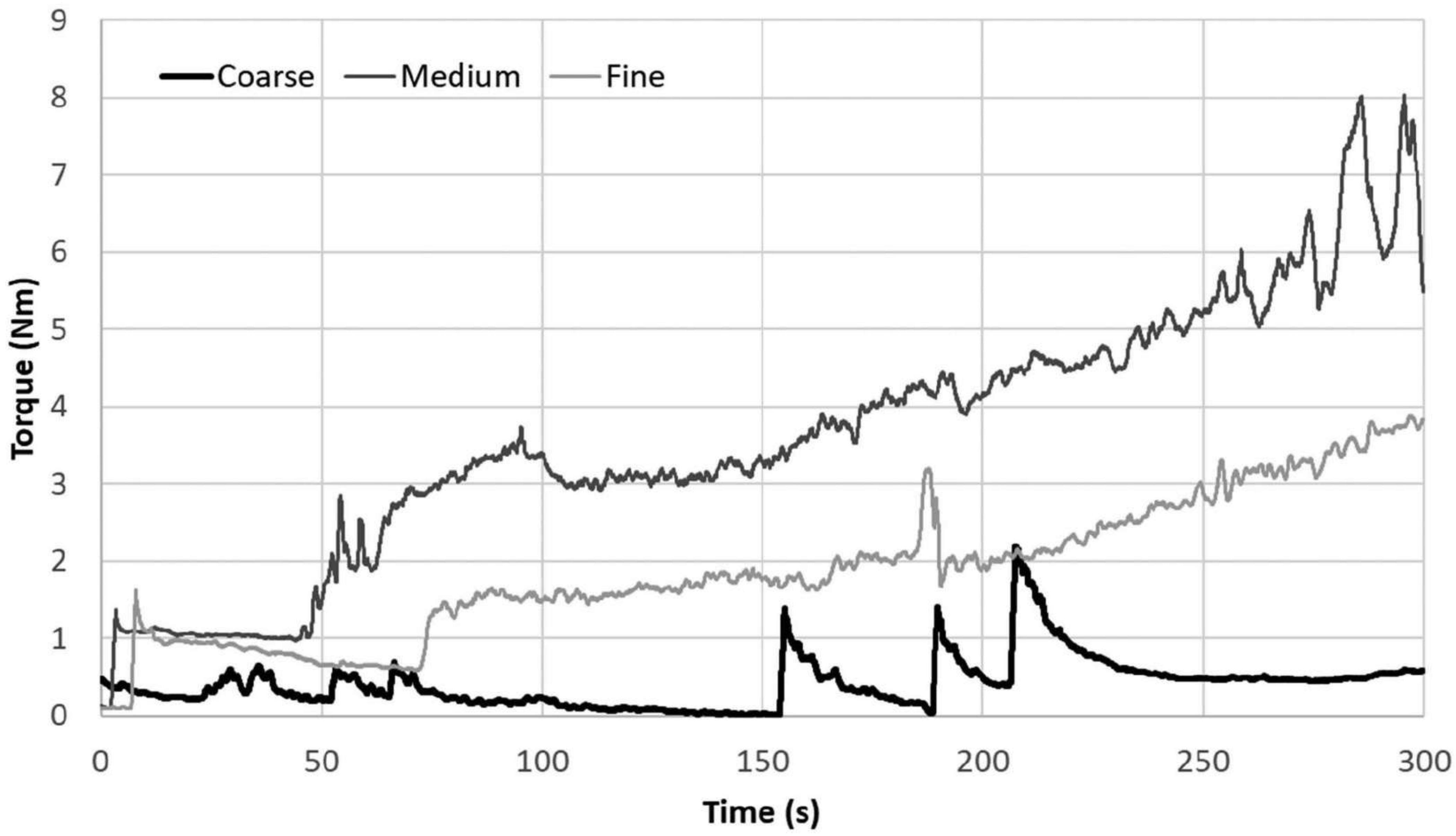

Figure 7. Results of tests.

4 CONCLUSIONS

The scientific researches related to EPB tunnelling in clay for the assessment of clogging risk and clogging potential are maily focused on the characterization of a homogeneous paste of the studied clay.

In the contrary, when considering the true process of excavation of an EPB, it is clear that the detached chips, have a decimetric size. These chips are not mixed long enough and with sufficient energy to form a completely homogeneous paste and the resulting material, that goes inside the bulk chamber, is a mix of a more or less liquid clayey mud inside which chips, differently hydrated in function of their dimensions, float.

Based on this physical consideration, a complete study of the clay conditioning for EPB tunnelling should consider the effect of the chip size distribution as already highlighted by Galli & Thewes (2014), Peila et al. (2016) and Todaro et al. (2022).

In this research the tests carried out have followed the same procedure and used the same conditioning parameters on 3 samples made of the same clay, but each sample has a different chip size distribution.

The results show a very different behaviour, with the coarse material being the least subject to clogging, the medium one the more subject to clogging, while the fine material, being homogeneous, shows a very good agreement with Hollmann & Thewes (2013) abacus.

This result is specific to the clay considered and its condition. In fact, the low clogging of the coarse material is due to the low natural water content. The same tests carried out on a clay that exhibits a strong clogging prior to conditioning would certainly lead to a different result and this research is underway.

This paper highlights the necessity to consider the chip size distribution in a complete study for the conditioning of clayey soils.

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