THE CUTTING OF CLAY: DIFFERENT METHODS TO PREDICT CLOGGING THE CUTTER HEAD

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ABSTRACT

Traditionally, contractors refrain from dredging clay, because they may encounter the problem of the excavated material sticking to the cutter and blocking transport to the suction mouth. Consequently, the operation has to be stopped to clear the cutter head and/or the suction mouth. To predict blockage, PIANC issued recommendations and are now widely used in the dredging industry. In a graph with Plasticity Index (PI) and Consistency Index (I_c), specific combinations of PI and I_c are indicated where no blockage to the cutter head and thus safe operation is expected. However, in practice, these specific combinations of PI and I_c may still lead to a blocked cutter. Or, the cutter is ok, but the inside and the suction mouth is completely blocked. This unpredictability is undesirable because it increases risk for delays and cost overruns. As a first step to overcome these problems, we reviewed the available scientific literature and otherwise publicly available documentation for a better understanding of the problems, the related physical phenomena and the operational factors involved. It appears that the PIANC recommendation was derived from a clogging problem in the tunnel boring industry. And along the way several assumptions and simplifications have been introduced, which might not be applicable for the dredging industry. A similar process with similar challenges is reported in the drilling industry. They experience a phenomenon 'bit balling' , where the chip is not properly transported away from the bit, causing it curl in front of the bit, balling up the chip. As the chip grows in size, it might clog the entire drill geometry. Next to several limiting soil conditions and operational parameters, the American Association of Drilling Engineers proposes to also do an analogy test where a metal shaft is rotated in a cell containing a soil sample under operating conditions. The accretion of clay on the shaft is a measure for the problems to be expected. In this test, the adhesion and remoulding of the clay is taken into account, which is neglected by PIANC and thus might improve the prediction of blockage in the dredging industry. Concluding, even though the operating conditions for drilling and dredging are different with a cutter functioning in a more open environment, we aim to develop a similar analogy test for the dredging industry, so clogging problems can be predicted better and the risk in dredging projects involving clay is reduced.

Keywords: Cutter clogging, bit balling, soil investigation, drilling, tunnelling.

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INTRODUCTION

The availability of suitable sand has become a limiting factor in the development of many ambitious reclamation projects, necessitating the reuse of other existing, less suitable materials for construction purposes (Hoffman et al., 2024). One common available material is clay. CROW, the Dutch institute 'Centrum voor Regelgeving en Onderzoek in de Grond-, Water- en Wegenbouw en de Verkeerstechniek' (Center for legislation in infrastructure) warned already about the material as of undesirable quality for the intended construction of infrastructure (Koster 2009) based on its carrying capacity through the shear strength and drainage and compacting characteristic through the permeability. Once the clay is in the pipeline system, it may create clay balls (balls of clay covered in sand) in the discharge line and consequently problems on the reclamation area (Boor et al. 2004) because of the poor load bearing capacity and slow dewatering.

However, dredging contractors are also hesitant for handling this material as it is known to stick to the cutter head, creating challenges in the excavation phase of the clay material. Potentially, it could block the suction mouth or pump (Figure 1). Consequently, the operation has to be halted to clean the cutter head and/or the suction mouth. Sometimes, the contractor has no choice in the material, e.g. when the clay is either the intended construction material, as well as when it is unexpectedly encountered in a maintenance project of capital dredging.

Figure 1. Blocked cutter head with highly plastic sticky clay.

Due to the operational risks in terms of costs and downtime, research has been conducted into the soil conditions that are likely to result in clogged cutters and suction mouths, or clay balls in the pipeline. For a clogged cutter this has been summarized into a recommendation presented by the PIANC (World Association for Waterborne Transport Infrastructure) (PIANC 2016) (Figure 2). The criteria for the adherence potentials are derived from research on the adhesion of clay related to the water content and the Atterberg limits for plastic limit and liquid limit. However, this narrow selection of soil parameters is insufficient when for the same Atterberg limits other parameters determine the behaviour of clay. e.g. When particular swelling clay is encountered, or when the electro-chemical charges of the particles differ from the values in the underlying research. In these conditions, the recommendations from the PIANC diagram are unreliable and the encountered clogging behaviour is unexpectedly different. This is mostly the case for active swelling clays, that can contain more water, and highly plastic clays where the adhesion is bound differently to the cohesion. Also, the PIANC diagram does not consider dynamic and hysteresis effects, which can severely offset the assumptions behind the recommendations.

This diagram proposed by PIANC has also been promoted in courseware (CEDA/IADC 2018). On closer inspection, the recommendation is not based on literature on dredging applications, but from the tunnel boring industry. Still, this recommendation is carried over into the CEDA/IADC recommendation for applying various types of dredging equipment to materials roughly characterized on a scale of cohesive to non-cohesive soils.

The recommendations from the CROW (Koster 2009) and PIANC (2016) are contradictory. On the one hand, the CROW recommends to use clay for construction within limits of a plasticity index (PI) of 20% to 90% and a consistency index (I_c) between 60% and 100%. Where the plasticity index is a parameter for the plasticity of the clay and independent of the current water content; the consistency index is a parameter for the firmness of the clay and does include the current water content of the clay. On the other hand, when plotted into the PIANC recommendation diagram (Figure 2) for the adherence potential for excavation, this area partly overlaps both the 'moderate adherence potential' and the 'high adherence potential'. Thus when selecting clay with the acceptable properties according to the CROW for construction it is likely to clog the cutter according to the criteria by the PIANC. Also, clay that is easy to handle according to PIANC, is unsuitable for construction according to CROW.

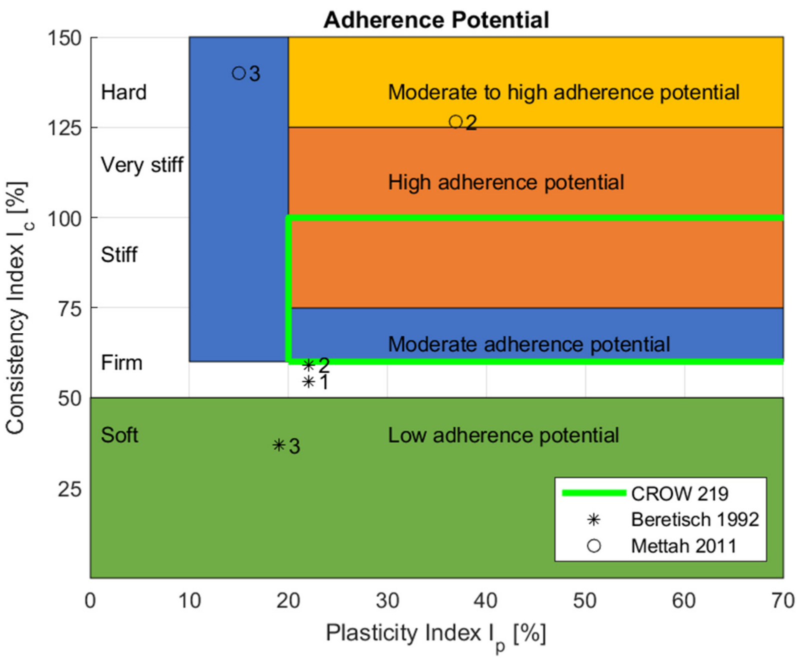

Figure 2. Recommendations of CROW (2009) and PIANC (2016) for the suitability of clay for dredging. Data points from Table 1 and Figure 3, point O1 outside of the presented range.

Next to the resulting conflict of the different recommendations, the recommendations themselves contain quite some uncertainty. Especially the PIANC themselves already identified the uncertainty in their recommendation by stating: 'As the data underlying this table was comprised of disparate sets of empirical data, the boundaries between low, medium and high adhesion potential should be regarded as indicators and not as firm boundaries' (PIANC 2016). This uncertainty may lead to incorrect estimations on the clogging risks in a project. Either the estimated risk is too high and the offered price will be too high and the contract will not be awarded or the higher price is passed on to the client without any extra benefit. Or the estimated risk is too low and problems might arise during the project and lead to time and cost overruns. Neither outcome is desirable and a more reliable estimation of the risks would enable more competitive contract bids.

Although the PIANC recommendation is based on research including adhesion. PIANC referenced research by Thewes (1999) that uses the relations between adhesion and water content found by Beretisch (1992) to simplify the limiting parameters to Plasticity Index and Consistency Index. There are some simplifications and assumptions where consequently adhesion is not included as a parameter in the criteria for suitable dredging material. And adhesion itself is a less understood phenomenon. Most research on adhesion is for dry conditions, while dredging is on wet clay, making the available literature even more irrelevant. When it is not possible to predict the clogging potential on the basis of the standard soil parameters, you need either a better relation between the clogging and those parameters or you need to measure the parameters involved in clogging, It is worth investigating whether a (simple) process experiment can be applied on actual samples taken from the bore hole campaign that provide better insight into the clogging potential of the material.

To improve on the prediction of clay being easy or difficult to dredge, similar clogging processes can be investigated and checked what parameters are used under those conditions. Particularly parameters that will include the dynamic conditions and remoulded soil that are encountered in the cutting process. This will enable checking the relevant parameters in a soil investigation instead of the normally provided parameters from a standard site investigation report (Wit et al. 2021).

In this literature review paper, the focus is on the clogging problems and not so much on the clay balls. For improving insight in this problem, the following questions will be investigated and answered:

- Why is the PIANC not always correctly predicting the clogging for the same Atterberg limits?
- Are there similar processes in other industries that face clogging also?
- What are recommendations and solutions there?
- Can these recommendations and solutions be applied in the dredging industry?

Eventually, the results of this review will be used to propose a standard test that is simple enough to be included in a soil investigation for checking if the soil is classified to have a ‘moderate or high adherence potential’ and will estimate the likelihood of a cutter head clogging in clay. This test will be further developed for its feasibility in the CHiPS program for Cutting Highly Plastic Soils initiated by Damen in cooperation with the Delft University of Technology.

PIANC CITERIA FOR CLOGGING IN DREDGING

In PIANC (2016) it is mostly up to the user to interpret the data for a production estimation. For clay, there are criteria provided with the recommendation on the adherence potential of clay and consequently the chance of clogging the cutter head, based on the indicated soil parameters. The actual recommendation is already displayed above (Figure 2). The adherence potential should be low to negligible below 10% Plasticity Index and below 60% Consistency Index. Remarkably, the recommendation is about the adhesion and clogging of the cutterhead, the parameters involved are only soil physical properties as Plasticity Index and Consistency Index.

Thewes (1999) argued to take the limits in the Plasticity index from the limits in the Plasticity Chart by Casagrande (1948). The 10% and 20% limits in the plasticity index correspond to the intersection with the ‘A-line’ for medium and high plasticity. The limits in the Consistency Index correspond with the classification proposed by Verbeek (1984), based on the correlation of Consistency Index and cohesion. The classification can still be seen in the left of (Figure 2).

One way to measure adhesion is by attaching a block or plate on the surface of the clay and pulling it away in the normal direction. The adhesion measured is a tensile stress. According to Schlick (1989) the tension adhesion is a factor 10 higher than the shear adhesion in the tangential direction. As the excavating process is mostly a shear adhesion of clay shearing over the surface of the blade, the adhesion potential is less representative for dredging. The adhesion can be measured at different water contents. This has been investigated by Beretisch (1992) (Figure 3).

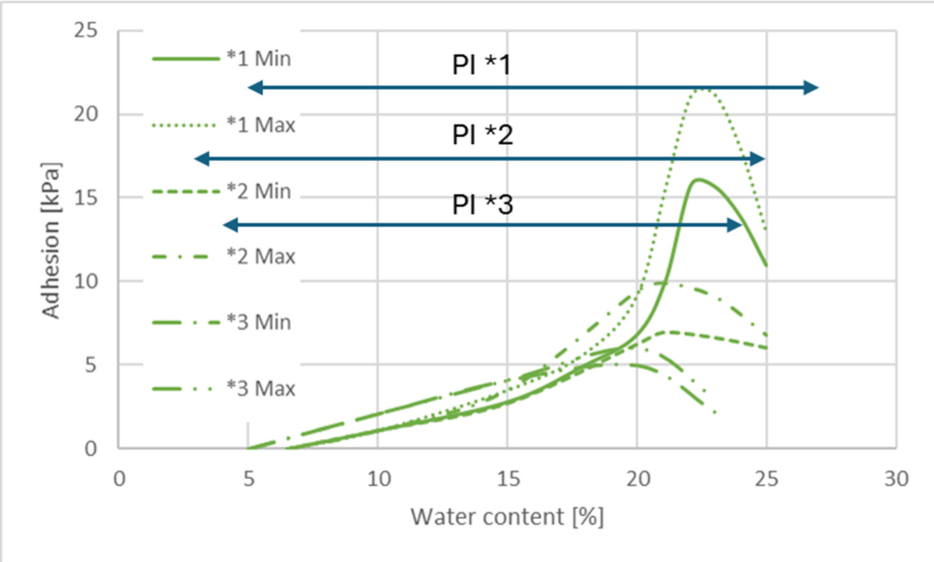

Figure 3. Various relations for adhesion and water content (Beretisch, 1992).

The trend of the adhesion in relation to the water content as seen by the data in (Figure 3) is in accordance with the model by Nichols (1931). Up to the plastic limit, the clay behaves like a solid block with a Coulomb friction coefficient. When the clay starts to get plastic, the adhesion starts to increase. Near the liquid limit, the adhesion will decrease, as the visco-elasticity will make it behave like a lubrication fluid. Even further past the liquid limit, the adhesion is eventually behaving like fluid with surface tension etc. As the background of the adherence potential categories is now known, it is interesting to check the data collected by Schlick (1989) for the adherence of soils in an operation with the recommendation by Thewes (1999) (Figure 4).

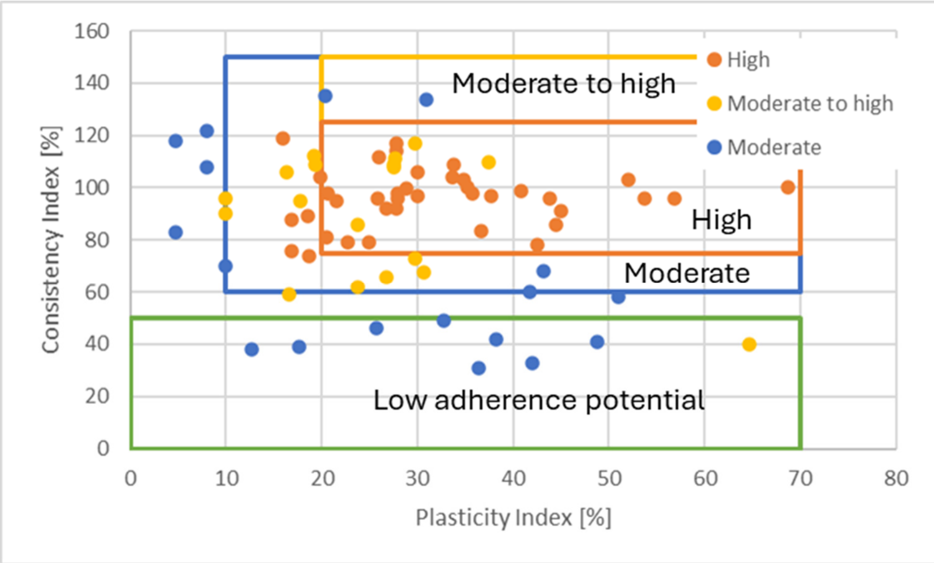

Figure 4. Data points (Schlick, 1989) as classified and limits by (Thewes, 1999). Legend similar to Figure 2.

The blocks are the same as the limits from Thewes (1999). The data dots from (Schlick, 1989) are in the corresponding colours of the adherence potential (moderate: blue, **moderate to high: yellow**, high: brown). It can be seen, that there is a remote correlation between the data points and the recommendation, but it shows, that the recommendation is indeed very week. Probably, the exact property that is directly related to the adherence potential: adhesion, is not correctly captured in the assumptions.

For tunnel construction with a pressure shield tunnel boring machine, a thorough evaluation in the relation between adhesion potential and the soil physical properties resulted in the aforementioned diagram of Figure 2 (Thewes 1999). However, for dredging applications, the situation is different and three issues need to be considered:

1. The adherence potential is based on an empirical relationship between the soil physical parameters and the adherence to a surface moving with the normal away from the clay specimen surface (tension). This is an unlikely situation in the dredging industry, where the movement of the clay is sliding (shearing) along the surfaces of the equipment.
2. The measurements of the soil physical parameters are the standard Atterberg Limits tests. These are specified to be on optimally conditioned specimens. As this is a perfect condition for a repeatable test, it does not reflect the conditions and the specific processes in a cutter head. By definition is the cut material disturbed. Due to the movement, the disturbed water pressures strain the material unpredictably and the water content is likely to be modified along the shear plane.
3. The conditions in tunnel boring are likely to be different from dredging. Most notably the ambient pressure (dredging: <30kPa; tunnel boring: > 100kPa)). But also, the likely clogging problem occurs in front of the suction mouth where bridges form when the clay adheres to the walls of the pressure chamber, where densities are higher and flows are slower. This is different from the problems seen in dredging where the flows are much more turbulent and the material adheres to the excavating surfaces of the cutter head on the outside and effectively blocking the flow before it enters the space before the suction mouth.

These issues are suspected to be the source of the discrepancies between the estimated adherence potential and the actual problems related to cutter head clogging. The first two issues are also recognized in the tunnel boring application. Later studies on the adherence potential improve the analysis of the soil parameters (Hollmann and Thewes 2013). Also the dynamic character of the tunnel boring has been addressed (Zumsteg and Puzrin 2012). They proposed a system with a plate rotating at a fixed shear rate in a cell filled with clay that is pressurized to the conditions in the tunnel boring machine (Figure 5). In this condition, the shearing adhesion and the sliding resistance are better represented and likely to provide a better prediction of the challenges encountered in the tunnelling industry

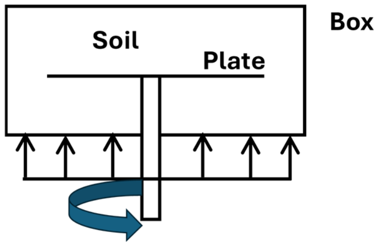

Figure 5. Shear cell for rotating plate test (Zumsteg and Puzrin, 2012).

In a closed cell, a block of clay is positioned around a plate. The block can be pressurized over the whole top or bottom area. The plate is attached on a shaft out of the cell. The torque to rotate the shaft and consequently the plate is measured. The torque is a measure for the sliding friction. Doing this test for various normal pressures will reveal the remaining adhesion under normal pressure. However, there is no solution found that sufficiently addresses the issues for the dredging industry. To improve the estimation of the adherence potential there, the integral approach has to be completely redesigned.

BIT BALLING IN THE OIL DRILLING INDUSTRY

When drilling for oil, geothermal energy or hydraulic (salt) mining a similar phenomenon is known: ‘bit balling’. Drilling for oil can be done with either a three conical rotating bit, or with a Polycrystalline Diamond Compact (PDC) bit. Both can suffer from bit balling and happens mostly when the drill bit is working in adhesive material like shale, mudstone or plastic clay and under the right conditions the sticky cuttings accumulate on top of each other and the drill bit is completely covered into a ball of clay (Figure 6).

Figure 6. Drill bit showing bit balling in a laboratory test (Mensa-Wimot 1997).

The Rate Of Penetration (ROP) decreases and the bit temperature increases, reducing the performance and bit life. Once this phenomenon occurs, the entire drill string has to be lifted to clean the drill and possibly the bits have to be replaced as well. This leads to excessive downtime and additional spare parts. As this is a nuisance this phenomenon has been thoroughly investigated, but it is still not sufficiently understood. There are some general soil conditions that provide an indication for the likelihood of bit balling:

- Mostly occurs with reactive clay or other adhesive materials like crushed shale.
- There must be water available for the reactive clay to absorb.
- The cut material is still compressed so there is negative excess pore pressure and the chip will tend to stick to surfaces.
- The clay is electrochemically active. The molecular bonds in the minerals are abundant. Specifically a high Cation Exchange Capacity (CEC).

These soil conditions are similar to the conditions in the dredging industry. It is relevant to compare this with the drilling industry which indicators for bit balling are identified. The PDC bit has the diamond bits arranged on arms. So, the actual cutting per bit is similar to the cutting with a dredging cutter head. Due to the different application in drilling, the geometry of the arms and the teeth orientation is different to the cutterhead. Notably, the cuttings from a drill bit are mixed with the transport fluid and pass along the side to the drilled shaft. In contrast, with a cutterhead they are sucked inside into a suction mouth. The operational parameters known to be involved in bit balling are:

- **Poor bit design**: The drill bit needs open space to transport the chip, but should also be confined enough for the jet flow to flush the process. When the application is not in balance with the design choices, this can cause problems in the operation.
- **Low flow conditions**: where the open space in the drill bit is not flushed sufficiently. Due to actual low capacity or because when the jets are diverted and loose their cleaning turbulence in areas not important to the cuttings flow.
- **Weight On Bit (WOB)**: The drilling process is force controlled, not motion controlled. When the WOB is increased, the resulting chip size is increased and these larger chips have a larger chance of clogging the flow channels. Especially when the flow is insufficient to support the transport and cleaning.
- **Hydrostatic pressure at the drilling depth**: The hydrostatic pressure can be controlled in the drilling process. And the pressure on the shear plane has an influence on the ductile behaviour of the cuttings.

Also, there are some general recommendations in the oil industry to prevent and recover bit balling.

- Change the viscosity and density of the drilling mud to control the turbulence in the space inside the drill bit to clean the chips from the bit surface. Not applicable for dredging.
- Use special lubricants to reduce the adhesion of the clay to the surfaces of the bit. Not applicable for dredging.
- Apply a procedure called ‘Hole Wiping’. This is essentially quickly move the drill up and down to shake the clay of the surfaces and create turbulence inside the drill bit to flush the clay of where the jet flows can’t reach the problematic areas. This is not directly transferable to dredging, but a similar remedy would be to shake the ladder or place jet nozzles inside the cutter head.
- Balance the flow rate of the drilling mud to the Rate Of Penetration (ROP) by modifying the applied Weight on Bit (WOB) or the drill fluid capacity. For dredging, this would equate to balancing the cutter speed with the step length, bank height and swing speed to match the pump capacity.

The cutting, sticking and clogging leading to bit balling are separate processes that can be individually investigated. In the drilling industry they have been investigated in detail to understand the cause of bit balling and to enable preventative and/or remedial procedures. One approach is to model the cutting process as a series of consecutive chips moving over each other in a discontinuous cutting regime. Using this approach, it was shown that when the chips stack too much on each other, the gap between the successive drill bit arms is filled resulting in back pressure of the plug and the shear stress on the bit surfaces, which causes the drill bit to ball up (Warren 1988). This happens when the total friction force immediately acting on the cuttings exceeds the compressive strength of the chip directly above the shear zone (Feenstra 1984; Che 2012).

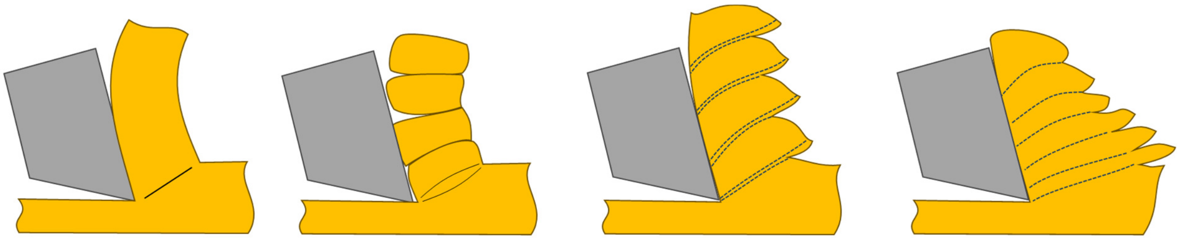

Figure 7. Chip accretion process in bit balling.

A quantitative model that can predict likelihood of bit balling is not yet available. Hence, the recommendation is to test samples under similar conditions as in the drill bit. A proposed procedure by the American Association of Drilling Engineers (AADE) in the oil industry is to quantify the accretion of clay on a rotating shaft in a sample cell (Mettah et al. 2011; Błaż 2019).

Figure 8. Accretion Test Cell – Solid Steel Bar (Błaż, 2019).

The test is executed as follows: a 50 gr clay sample is enclosed in a stainless steel container. In the middle of the sample, a loose cylindrical bar is introduced. The rest of the container is filled with the drilling fluid under investigation. The container is closed and placed on a roller drive. After a predetermined time the container is opened. The bar is scraped clean and the material that has accreted on the bar is weighed. The accretion is calculated according to (Eq. (1):

$$Acc = \frac{W_3}{\left(\frac{100-M_i}{100}\right)W_1} 100\% \quad (1)$$

The accretion percentage (Acc) is related to the mass sticking on shaft (W_3) to the original mass (W_1), corrected for water content of sample (M_i). Multiple samples are tested for the accretion percentage at different time intervals. (Figure 9)

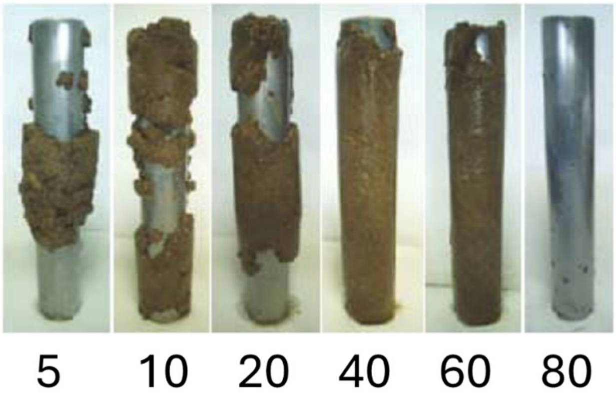

Figure 9. Accretion profile over 5, 10, 20, 40, 60 and 80 minutes (Mettah et al. 2011).

Remarkably some combinations of clay and fluid will either leave a completely clean roller bar, or remain at a certain accretion percentage and stay at that level beyond the measured time frame. The combination of clay and metals that show this sticky behaviour are more likely to display bit balling (Figure 9). Mettah et al. (2011) used three clay types: Oxford Clay, Arne Clay and Lilebaelt Clay with the following properties (Table 1)

Table 1. Soil properties of the (Mettah et al. 2011) experiments.

		Provided			**Analysed**	
ID	**Sample**	**w(%)**	**I_p(%)**	**I_l(%)**	**PI(%)**	**I_c(%)**
1	Oxford	3.4	25.7	40.9	15.2	246.7
2	Arne	26.5	36.3	73.2	36.9	126.6
3	Lilebaelt	20.5	26.5	41.5	15.0	140.0

The soil properties provided in the Mettah et al. (2011) article have been analysed for their Plasticity Index and Consistency Index. These values have been included in the adherence potential diagram (Figure 2). According to the criteria, the Arne Clay and the Lilebaelt Clay, respectively, have a moderate to high and moderate adherence potential. The Oxford Clay has a consistency index that is out of the scope. The high Consistency Index and low water content indicate this was a very stiff and dry clay, with at least moderate adherence potential.

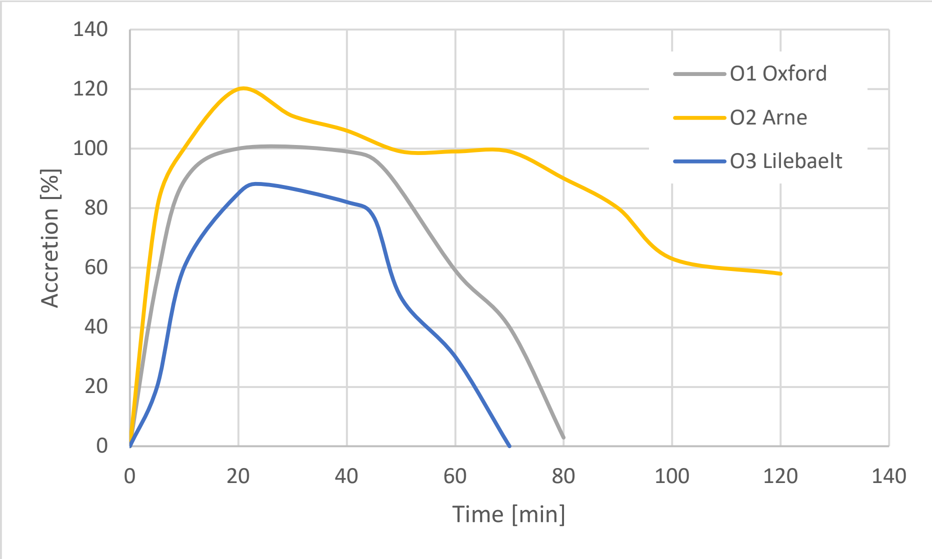

Figure 10. Accretion profiles of the different outcrop clays (Mettah et al., 2011).

Figure 10 shows the outcome of such a clay accretion experiment. All clays have zero accretion at the start of the experiment. This indicates that these clays are not near their adhesion limit. It would be interesting to investigate the influence of the adhesion limit of this experiment. The Oxford Clay and Lilebaelt Clay do start with accretion that over time is lost again. After 70 and 80 minutes, the roller bar can be removed without any adhering clay. In this case, the 'Arne Clay' is likely to display bit balling, the others will run clean eventually. As the accretion percentage is intrinsically already corrected for changes in water content, the actual values can surpass 100%, as in the case of the 'Oxford Clay' and 'Arne Clay'. It is not, that there is a magical generation of clay inside the cell. This rolling bar test can be modified to test multiple parameters as: water content, tool materials, pressures and temperatures, coatings, lubrication fluids, etc. (Błaż 2019).

DISCUSSING THE DREDGING, TUNNELLING AND DRILLING CLOGGING CRITERIA

Firstly, the phenomena of cutter clogging and bit balling are similar. Both happen in similar clays. They have the same result of blocking the passage between the arms. The blocking in tunnelling investigated by Thewes (1999) on the other hand is related to the blockage of the suction mouth in the pressure chamber. The main differences are due to the open and closed environments of the processes and where the transport water comes from and the time scale (Table 2).

Table 2. Difference between cutter clogging and bit balling.

ID	Criteria	Cutter clogging	Tunnelling	Bit balling
1	**Transport water source**	External	Pressurised	Internal
2	**Transport fluid type**	Ambient water	Drill fluid (can be water based)	Drill fluid (can be water based)
3	**Tool diameter**	>1000mm	>1000mm	<300mm
4	**Time frame**	Seconds	Minutes	<Hour
5	**Clogging mechanism**	Cutting related	Suction flow related	Cutting related

The transport fluid in the tunnelling industry is in most conditions a drilling mud based on water provide in the pressure chamber. That condition is similar to the dredging process where the process fluid is also water, although from the environment. As the dimensions of the pressure chamber and the cutter head for the larger dredges is in the same range, it is understandable that the dredging industry sought inspiration in the tunnelling industry for adhesion potential criteria. However, cutter clogging is a cutting related problem, while the tunnelling model is related to blocking the suction mouth. This might give inaccurate estimations. e.g., when the clay is highly active or adhesive. Conversely, the bit balling is a cutting related problem, similar to the cutter clogging. Therefore the bit balling criteria could be interesting for estimating the cutter clogging potential.

The method for estimating the adherence potential according to the PIANC is relatively straight forward and can be performed with the Atterberg limits and the water content. Those are soil parameters that should be available in reports on the soil investigation (Kinlan 2014; PIANC 2016). However, these basic soil parameters are unrelated to the operating conditions of the process. Conversely, the rolling bar test is a special additional test, generally not included in the soil investigation. It could be performed on samples from the bore logs, as the required amount is relatively small. The advantage of the rolling bar test is that it is a dynamic test, mimicking the shear conditions of the cutting process. And the shearing also causes the sample to be remoulded. Just as cut material is remoulded by definition. Before adopting the rolling bar test for the cutter clogging estimation in the dredging industry, there are some issues that have to be addressed.

1 Similar to bit balling, cutter clogging is also influenced by the flow conditions of the transport fluid. This is not included in the experiment, it only checks the adherence under dynamic conditions.
2 The time scales that these experiments are normally run, are typical for the oil industry and less likely in the dredging industry. Bit balling is a problem that only arises over time and is noticed later. Whereas cutter clogging is a relatively rapid process and has a shorter time until it is noticed by the operator. It has to be investigated whether the duration of the test under dredging conditions is typically shorter. When the test is not shorter, the longer test have to be checked to be still representing the clogging potential in dredging.
3 As cutter clogging is a rapid process, it may be investigated whether there is also information to be found in the first phases of the rolling bar test. e.g. Similar to the adhesion limit test of Atterberg with clay dripping from a spatula, but then at prescribed rates and duration.
4 The recommendation for the rolling bar test is to use a stainless steel class 315 container and bar material. Stainless steel has a lower adhesion than normal steel (Winkelman, 2024). It can be checked whether materials usually applied in the dredging industry have a better response and give more representative test results.
5 Ultimately, it would be helpful to have a correlation between the results of a modified rolling bar test for dredging and real field data on actual cutter clogging.

It might also be considered whether the intrinsic correction for the original water content in the sample has to be included in the calculation of the accretion percentage. It might also be externally calculated and only the clay mass is included in the accretion calculation. This prevents the overshoot over the 100 % and may be more intuitively analysed.

CONCLUSIONS

Considering the review of the PIANC recommendation and the review of the rolling bar test, the following conclusions can be drawn:

1. It is crucial for the dredging industry to estimate the risk of cutter clogging accurately for determining the contract price optimally. Especially as the clay material most likely to be used for construction in a dredging project is also the most likely to give problems in the handling during dredging according to the recommendation issued by PIANC.
2. The PIANC recommendations for adherence potential will be unreliable when the clay is highly active or the adhesion is less related to the cohesion, as the dynamic behaviour of the clay is not correctly included.
3. The proposed rolling bar test as used in the drilling industry includes the dynamic behaviour of the clay. Moreover, the test also can include the inclusion of soil parameters as: adhesion, cation exchange capacity and process parameters as shear rate and pressure.
4. In situations where the program of the site investigation is negotiable, the rolling bar test modified for dredging applications should be discussed for inclusion.

It is recommended to investigate whether the rolling bar test can be used to provide a better estimation of the clogging potential in dredging applications, e.g. a dredging cutter head. A test program for this purpose is being developed in the CHiPS project.

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