Investigating inherent mechanism of loess adhered to shield machine cutting tools

Author

Bai, XD, Cheng, WC, Wu, B, Ong, DEL

Published

2024

Book Title

Geotechnical Aspects of Underground Construction in Soft Ground

Version

Version of Record (VoR)

DOI

10.1201/9781003413790-42

Rights statement

Downloaded from

Griffith Research Online

Geotechnical Aspects of Underground Construction in Soft Ground – Zhou, Guan & Li (eds)

Investigating inherent mechanism of loess adhered to shield machine cutting tools

X.D. Bai, W.C. Cheng & B. Wu
Xi'an University of Architecture and Technology, Xi'an, China

D.E.L. Ong
Griffith University, Queensland, Australia

ABSTRACT: Soils adhered to cutting tools or clumped to each other could not only cause a low advance rate in tunneling but also a difficulty in spoil discharging. These results especially hold true while tunneling in the loess containing primarily silt particles. The above remains to be addressed toward preventing unplanned downtimes and additional project costs. In addition to the mixing and fluidity tests, the atomic force microscopy (AFM) test is applied in the present work to explore the inherent mechanism affecting their adhesion properties when sand, kaolinite, and montmorillonite are introduced as adhesion reduction materials. The adhesion ratio is in a negative relation with the fluidity. The latter two are deemed poor adhesion reduction materials despite the higher adhesion force of the sand-loess mixture than the kaolinite-loess mixture. The intermolecular force plays a key role in promoting such a phenomenon. The highest adhesion force of 52.5 nN is attained by the montmorillonite-loess mixture due to the development of capillary force.

1 INTRODUCTION

Cohesive soils often adhere to cutting tools of a shield machine, increasing the clogging potential [1-2]. Based on existing theories, the adhesion formed at soil-metal interface can be divided into three categories [3]. The intermolecular force controls the adhesion force when a small amount of water is present at the soil-metal interface. With the increase of moisture content, water rings are formed between soil particles and metal, and the physical interaction represented by capillary tension controls the adhesion force. When water rings penetrate with increasing moisture content and form a water film, the water film (capillary) tension is considered to be the key factor affecting the adhesion force [4-5]. Loess which is an aeolian sediment is widespread in Northwest China and contains mainly silt particles. Although previous studies have largely improved our understanding of the development of the adhesion force, the inherent mechanism affecting the loess adhered to cutting tools has not been explored yet. The above reveals some research gaps and shortcomings. The main objectives of this study are to: (1) explore the inherent mechanism affecting the loess adhered to cutting tools; and (2) propose countermeasures applied to reducing the adhesion force toward preventing unplanned downtimes and additional costs while tunnelling in Northwest China.

2 MATERIALS AND METHODS

The loess containing a higher than 85% silt fraction was classified as low plasticity clay according to the Unified Soil Classification System (USCS). Kaolinite and montmorillonite are the main components of the bentonite slurry applied to counterbalance chamber pressures

DOI: 10.1201/9781003413790-42

exerted during shield tunneling. By contrast, the mechanical properties of sand are not governed by Van der Waals forces but by gravity forces. To this end, it is applied accentuating their relative merits. In the present work, sand, kaolin, and montmorillonite are used as additives to explore their effect on the adhesion force and fluidity of the soil mixtures. Laboratory tests applied to the present work mainly included mixing, fluidity, and atomic force microscopy (AFM) tests. The mixing test aimed to determine the adhesion potential through the adhesion ratio. Soil specimens at different additive proportions and moisture contents were first mixed using an agitator and stood still. When it started falling from the agitator, the remaining was weighed. The measurement was repeated 7 times and 5 out of the readings were applied to determine the adhesion ratio (see Equation 1).

$$\lambda = \frac{1}{5} \sum_{x \in \{0,1,2,3,7\}} \frac{G_{MTx}}{G_{TOT}} \tag{1}$$

where G_{MTx} is the adhesion mass of soil after x numbers of drops; G_{TOT} is the total mass of soil; λ is the average adhesion ratio obtained. Furthermore, the fluidity of soil specimens was determined by the difference in specimen diameter before and after vibrations (see Equation 2).

$$Flow_{25} = \frac{d_{25} - d_0}{d_0} \times 100\% \tag{2}$$

3 RESULTS AND DISCUSSION

3.1 *Results of sand-loess mixture*

The maximum adhesion ratio of the sand-loess mixture decreases with the increasing sand fraction (see Figure 1). The reduction in adhesion starts taking effect as the sand fraction is in excess of 30%. The soil consistency I_c of the sand-loess mixture remains in a 0.2-0.4 range when subjected either to a high sand fraction or a low sand fraction (see Figure 4). Further, results from the AFM tests show that the surface morphology varies notably with the highest difference in elevation being 20 nm toward reducing the contact between the loess and the metal probe and then the adhesion force (see Figure 3). Moreover, results also show that the fluidity of the sand-loess mixture increases with increasing sand fraction and that the fluidity against the soil consistency I_c of 0.2 is rather close to that against the soil consistency I_c of 0 (corresponding to the liquid limit of the sand-loess mixture) (see Figure 2). The higher the fluidity, the lower the potential for the spoils to clump together, and the smaller the difficulty for spoil discharging. On the whole, the sand addition can effectively reduce the adhesion between the loess and the metal, preventing difficulties in cutting. The increase in fluidity by the sand addition can also prevent clogging in spoil discharging. In light of the above, the sand addition is considered as a good adhesion reduction material, preventing unplanned downtimes and additional project costs.

3.2 *Results of kaolinite-loess mixture*

The maximum adhesion ratio of the kaolinite-loess mixture remains above 0.4 when subjected either to a low kaolinite fraction or a high kaolinite fraction, indicating a high potential of adhesion to cutting tools (see Figure 5). Under this circumstance, the soil consistency falls within a 0.5-0.75 range (see Figure 8). Results from the AFM test show that the surface topography does not vary as significantly as that of the sand-loess mixture, with the highest difference in surface elevation of 3 nm, corresponding to a larger contact area (see Figure 7). The adhesion force is supposed to be higher under this circumstance. However, the adhesion force is higher in the sand-loess mixture (31.4 nN) than in the kaolinite-loess mixture (25.8 nN).

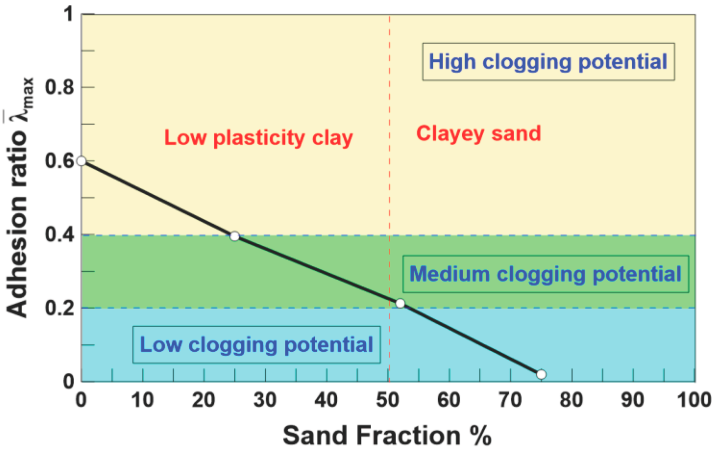

Figure 1. Mixing test results applied to the sand-loess mixture.

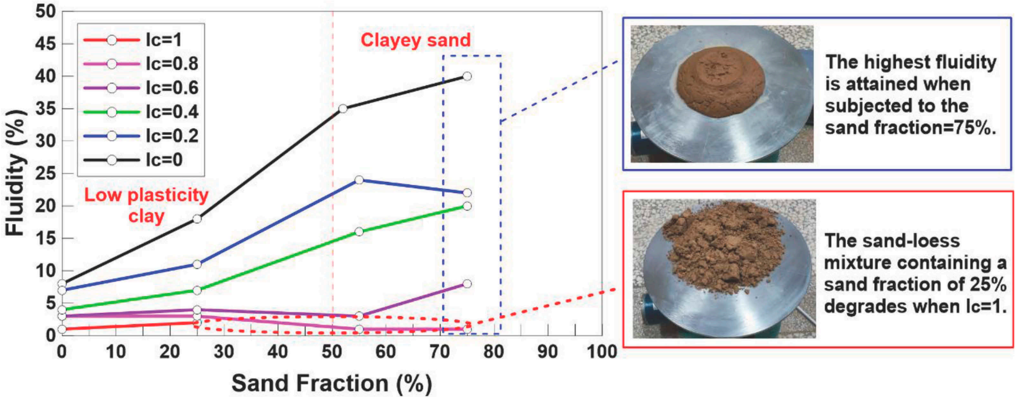

Figure 2. Fluidity test results applied to the sand-loess mixture.

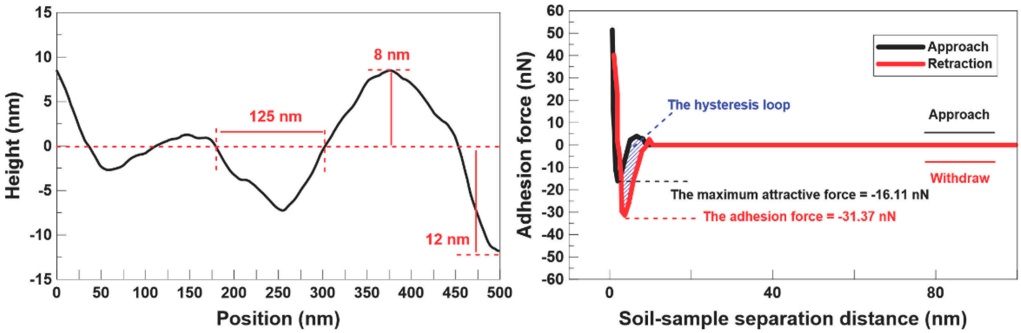

Figure 3. AFM test results applied to the sand-loess mixture.

This is mainly attributed to the non-swelling nature of the kaolinite, preventing water intrusion. The adhesion cannot be developed until water intrudes the DDL (diffuse double layer). As to the sand-loess mixture, its adhesion is not dominated by the capillary tension but by the intermolecular force. Apart from that, the fluidity of the kaolinite-loess mixture against I_c = 0.6 (which is within a 0.5-0.75 range) is rather low, meaning that the kaolinite-loess mixture not

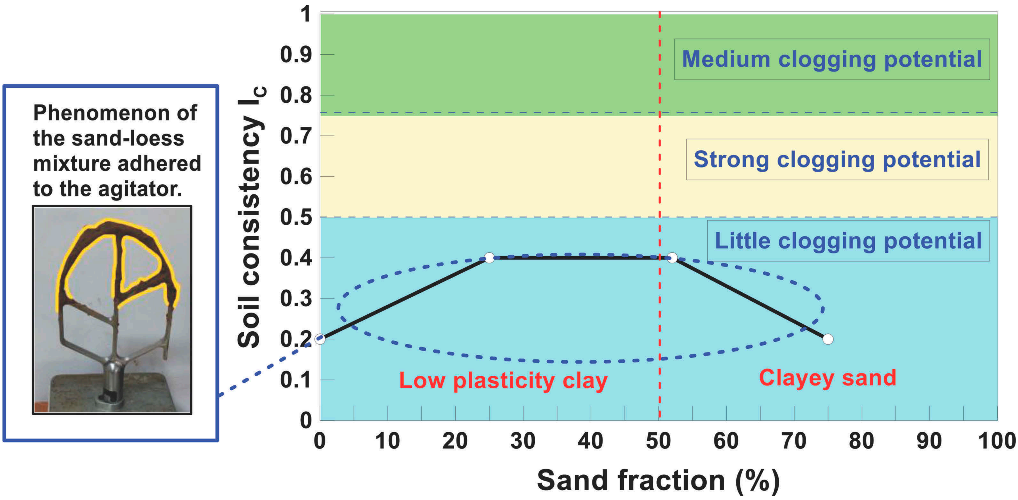

Figure 4. Relationship of consistency index versus sand fraction applied to the sand-loess mixture.

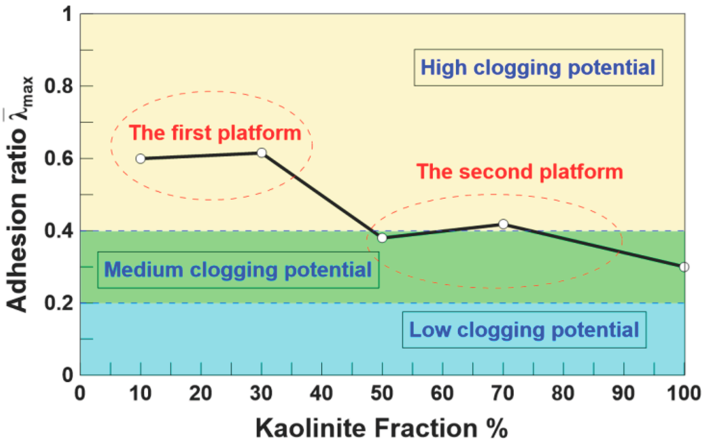

Figure 5. Mixing test results applied to the kaolinite-loess mixture.

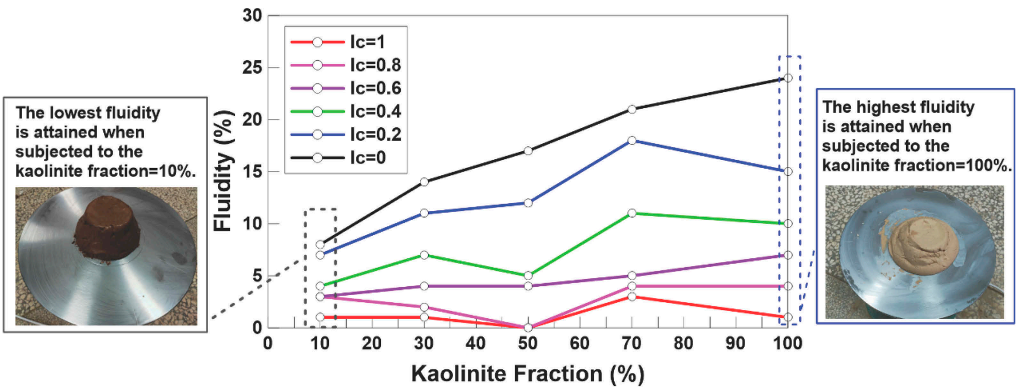

Figure 6. Fluidity test results applied to the kaolinite-loess mixture.

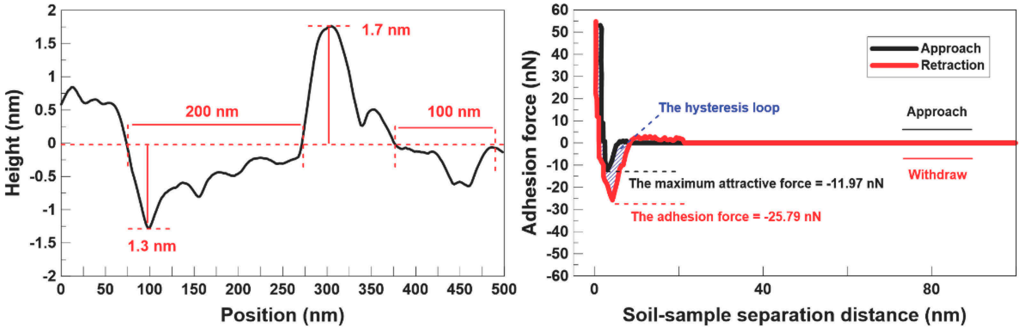

Figure 7. AFM test results applied to the kaolinite-loess mixture.

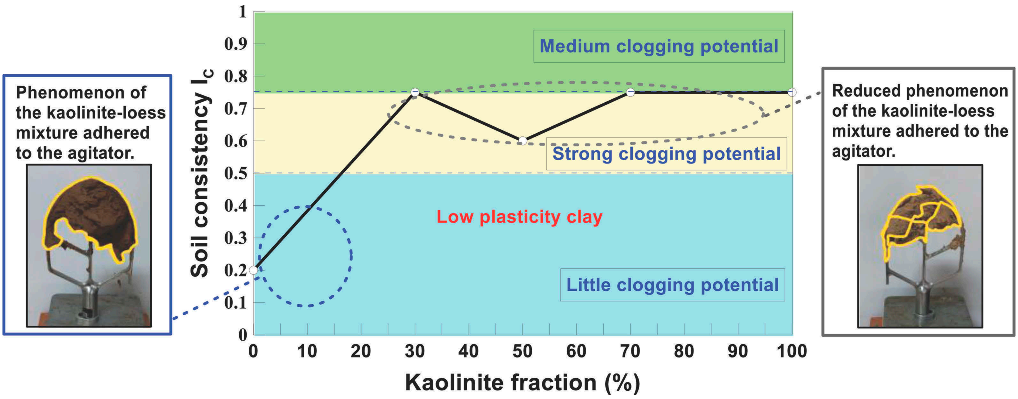

Figure 8. Relationship of consistency index versus sand fraction applied to the kaolinite-loess mixture.

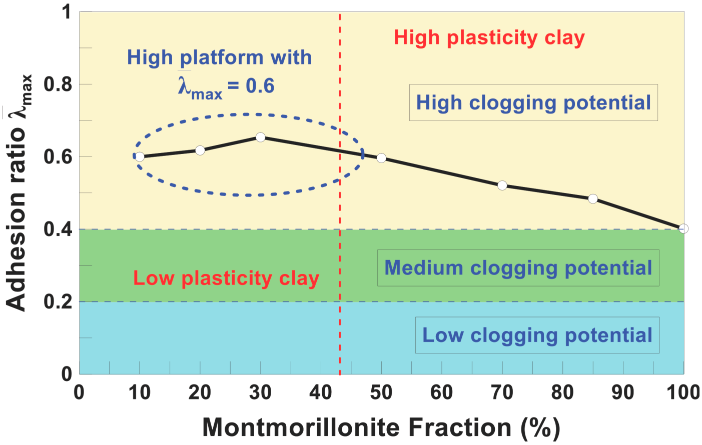

Figure 9. Mixing test results applied to the montmorillonite-loess mixture.

only has a high potential to adhere to cutting tools but can easily clump together, causing a clogging problem in spoil discharging (see Figure 6). In short, the kaolinite addition cannot be considered a good adhesion reduction material.

3.3 *Results of montmorillonite-loess mixture*

The maximum adhesion ratio of the montmorillonite-loess mixture is way higher than that of the kaolinite-loess mixture, corresponding to a maximum adhesion ratio of above 0.6 (see Figure 9). Under this circumstance, the soil consistency falls also within a 0.5-0.75 range (see Figure 12). Results from the AFM test indicate that the montmorillonite-loess mixture has the lowest roughness (smallest difference in surface elevation) and the adhesion force being 52.5

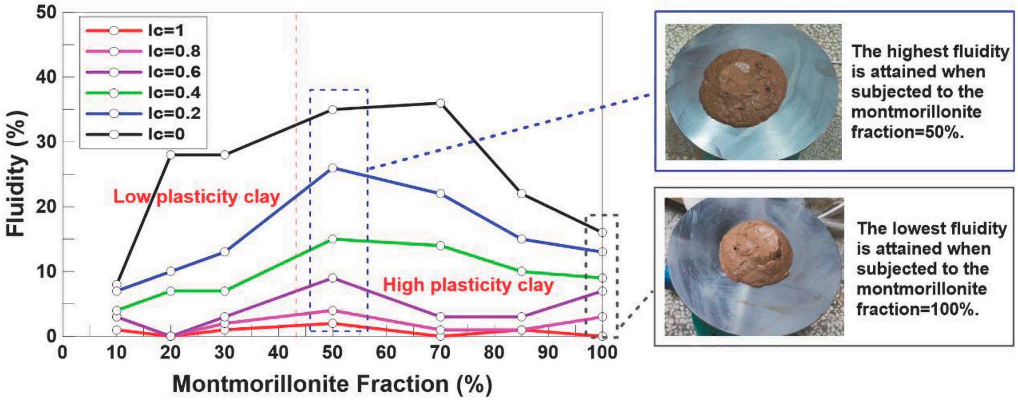

Figure 10. Fluidity test results applied to the montmorillonite-loess mixture.

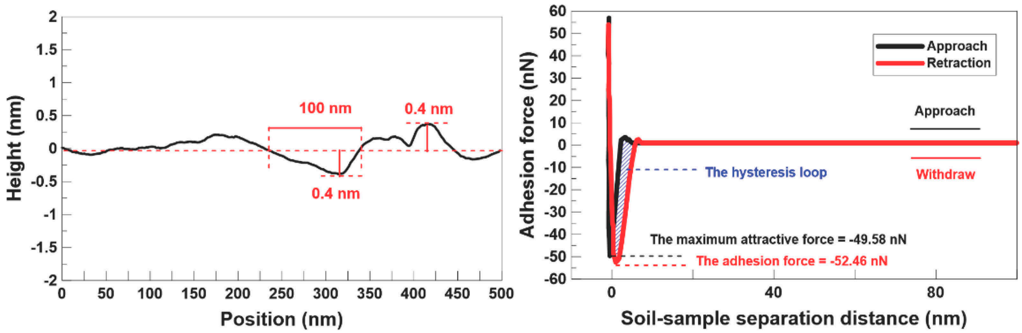

Figure 11. AFM test results applied to the montmorillonite-loess mixture.

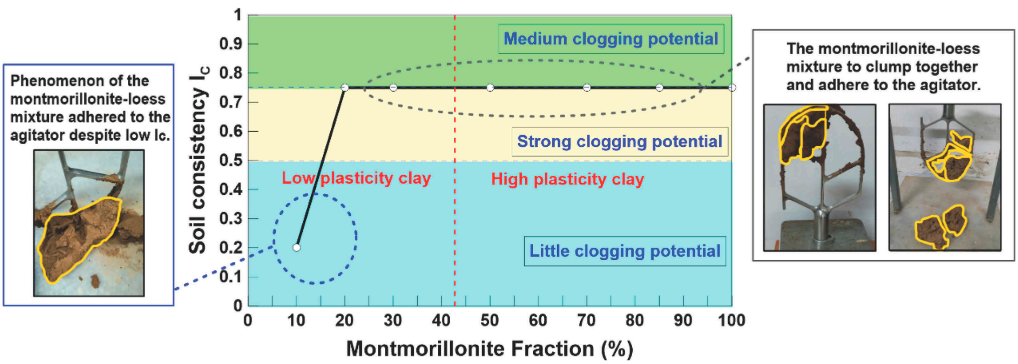

Figure 12. Relationship of consistency index versus sand fraction applied to the montmorillonite-loess mixture.

nN (the highest in the present work) (see Figure 11). On the other hand, the fluidity of the montmorillonite-loess mixture against I_c = 0.6 (which is within a 0.5-0.75 range) is extremely low. These results correspond to a high potential for it to clump together and also a significant clogging phenomenon in spoil discharging (see Figure 10).

4 CONCLUSIONS

Based on the results and discussion, some main conclusions can be drawn as follows. The higher the adhesion ratio, the lower the fluidity. The use of kaolinite and montmorillonite are not deemed as good adhesion reduction materials despite the higher adhesion force of the sand-loess mixture than that of the kaolinite-loess mixture. The intermolecular force plays a leading role in triggering such a phenomenon. The highest adhesion force of 52.5 nN is attained by the montmorillonite-loess mixture, most likely due to the development of the capillary force.

REFERENCES

Zumsteg, R., Puzrin, A. 2012. Stickiness and adhesion of conditioned clay pastes. *Tunnelling & Underground Space Technology* 31: 86–96.

Wang, S., Liu, P., Hu, Q., Zhong, J. 2020. Effect of dispersant on the tangential adhesion strength between clay and metal for EPB shield tunnelling. *Tunnelling & Underground Space Technology* 95: 103144.

Fountaine, E.R. 1954. Investigations into the mechanism of soil adhesion. *European Journal of Soil Science* 5(2): 251–263.

Wan, Z., Li, S., Yuan, C. 2021. Soil conditioning for EPB shield tunneling in silty clay and weathered mudstone. *International journal of geomechanics* 21(9): 06021020.

de Oliveira, D.G.G., Thewes, M., Diederichs, M.S. 2019. Clogging and flow assessment of cohesive soils for EPB tunnelling: Proposed laboratory tests for soil characterisation. *Tunnelling & Underground Space Technology* 94: 103110.