Analysis on Research Status of Loess Microstructure

Xiao Xie 1,2,3,4,a, Yulu Wei 1,2,3,4,b

1 Shanxi Province Land Engineering Construction Group;
2 Institute of Shaanxi Land Engineering and Technology Co., Ltd.;
3 Key Laboratory of Degraded and Unused Land Consolidation Engineering, the Ministry of Natural Resources;
4 Shaanxi Provincial Land Consolidation Engineering Technology Research Center
xi’an, 710075, China

a 2015126008@chd.edu.cn
b weiyulu97@qq.com

Abstract. Chinese loess has a wide range of distribution, large strata thickness, and high stratigraphic completeness, and has been widely studied by scholars. By consulting and summarizing literatures, this paper generalizes the previous research results, and summarizes the microstructure characteristics of the loess, such as loess skeleton particles, the way they are connected to each other, the pore types, and the regional changes of the loess microstructure. Finally, the prospects of relevant researches on the loess microstructure were prospected.

1. INTRODUCTION

The microstructure of loess refers to the soil microstructure observed under a microscope. It includes single mineral particles, aggregates composed of multiple minerals, cementing materials, pores and other structural units, and also the combination and connection mode of each structural unit. With the influence of the external environment, the change of loess deformation and strength has always been a research focus in the field of geotechnical engineering. In the final analysis, these changes are caused by the microstructure of the loess. That is to say, the microstructure plays a decisive role in changing the macroscopic properties of the soil.

Loess has metastable structure [1], and it is a reliable method to reflect the structure of the loess through the study of the microstructure of the loess. Numerous research [2-5] results show that the physical and mechanical and engineering properties of loess are closely related to its microstructure. Feng Wang et al [6], took Lanzhou remolded loess with different densities as the research object, and revealed the fact that the hydraulic parameters of soil depend on its microstructure. Gao Lingxia et al. [2] studied the deformation mechanism and influencing factors of unsaturated loess, based on the suction theory of unsaturated soil and the microstructure characteristics of loess. Zhang Yuchuan et al. [7] obtained the SEM scanning photos by means of an electron microscope through laboratory collapsing and seismic subsidence tests, compared and analyzed the collapsibility and seismic subsidence of loess from a structural perspective. Hu Ruilin et al. [8] revealed experimentally the microstructure control mechanism of macroscopic deformation of loess.

As can be seen from the above description, on one hand, the microstructure of the loess reflects the formation conditions of the soil mass and the characteristics of its existing environment; on the other
hand, it is also the decisive factor for the change of the macro engineering properties of the loess. Therefore, studying the microstructure of the loess can not only identify the inherent structural characteristics of the loess, and infer its formation conditions, but also help to identify the relationship between the changes in macro engineering properties and the microstructure, and better explain the changes in the macro mechanical properties of the loess.

2. Basic Characteristics of Loess Microstructure

As mentioned earlier, the microstructure of the loess includes many elements. This section mainly introduces the microstructure characteristics of the loess from the aspects of the skeleton particle, arrangement and contact of the skeleton particle, and pores in the loess.

2.1. Composition of skeleton particles in loess

The mineral composition of loess in China is basically the same[9]. It mainly contains fine clastic quartz, feldspar, calcite, mica, illite, and chlorite in clay minerals, but there is little kaolinite and montmorillonite. Gao Guorui[10] observed Lanzhou loess by electron microscopy and found that some of the skeleton particles were primitive mineral debris, and some were aggregates formed by very small particles, or the particles were coated on the surface of the debris to form outer clay particles. The aggregates are cemented from microcrystalline calcium carbonate. Clay and colloidal particles are present in the loess as aggregates or coated on the surface of the particles.

2.2. Contact and arrangement of loess skeleton particles

Microstructure pictures show that there are two types of contact modes, namely, surface to surface and point to point contact[11]. Point to point contact often occurs between rigid aggregates and debris particles, and the contact surface is positively small. When the contact area between the particles is large, it is called surface to surface contact. There is a thick clay film or a large number of clay flakes at the contact point, and the salt crystal coating is also connected.

2.3. Classification of pores in the loess

Loess pores are classified in a variety of ways. Some researchers classified the pores based on the pore size. For example, according to the equivalent radius of the pore, Ma Fuli et al. [12] divided the pores in the loess into five types, namely extra-large pores (equivalent pore radius > 50 μm), large pores (20 μm-50 μm), medium pores (5μm ~ 20μm), small pores (2μm ~ 5μm), and micropores (<2μm). There are also classifications that devided pores in the loess into primary pores and secondary pores according to genetic types. In addition, there are also classifications based on causes and sizes. By comprehensive considering field observations, polarized light microscopes, scanning electron microscopy, and mercury intrusion test results, Lei Xiangyi[13] divided the loess pores into the following types according to their genetic types, of which the first two belong to primary pores and the latter five are secondary pores.

(1) Intergranular pores

Intergranular pores are the spaces between the grids composed of skeletal particles. This type of pores is the main component of the loess pores. According to the arrangement of the framework particles, the inter-particle pores can be divided into scaffold pores and mosaic pores. The pores formed by the skeleton particles supporting each other are scaffold pores (Figure 1a). These kinds of pores are generally larger, sometimes even larger than the diameter of the particles that make up it, but they have poor firmness. Under the action of water and pressure, the loess with scaffold pores is prone to collapsing because of low connection strength. Mosaic pores are formed by soil skeleton particles interspersed with each other and densely packed (Figure 1b), which are mostly gap-shaped and relatively smaller and more stable than the scaffold pores. The number of scaffold pores and mosaic pores in the loess is determined by the particle size composition, the arrangement of particles, the strength of weathering to soil, and the degree of compaction to the loess soil.

(2) Intragranular pores
If the intergranular pores are filled with cohesive matter, then cement pores are formed (Figure 1c). Cement pores are also called intragranular pores. This kind of pores has a large number, but its volume is small, its connectivity and water permeability are poor, its stability is good, and it is not easy to produce collapse. The content of cement pores in the soil is proportional to the content of clay content. From the north to the south and the west to the east in spatial distribution, the geological age from new to old, the clay content in the loess gradually increased, and the content of cement pores also increased significantly.

3) Root holes
   Root holes are formed by the plant root system extending along the intergranular gaps or other weak parts during the growing process. The hole walls are dense and tidiness. The large pores that we usually notice are mainly such pores. The wall of the root hole is often cemented by substances such as secondary calcium carbonate to form a pipe, so that the root hole will not aggravate the collapse, and also actively resist the occurrence of the collapse.

4) Insect hole
   The hole left in the soil during the process the mud-eating vermes or other arthropod drilling and live is the insect hole. Because the animal swallowed or removed the soil particles in the hole, the hole wall was less dense than the root hole. Insect holes are more common in the surface layer of loess.

5) Mouse hole
   Mouse holes are mainly distributed on the top of the late Pleistocene loess, and are cylindrical.

6) Joint and fracture
   The commonly distributed vertical joint is is an important feature of loess. Fissures are rare in sandy loess and more common in cohesive loess. Joints and fissures in loess are more common in older soil layers, which seriously threaten the stability of embankments and slopes.

2.4. Regional characteristics of loess microstructure
   Typical loess in China is mainly distributed in the six provinces of the middle Yellow River region \(^[2]\), namely: Gansu, Ningxia, Shaanxi, Shanxi, Henan, and Hebei. As mentioned earlier, the mineral composition of loess is basically the same, but due to different climatic conditions and geological environments, there are obvious differences in the loess microstructures in different regions. Gao Guorui et al. \(^[14]\) revealed the regional changes of the microstructure of the loess through research and observation of SEM pictures. The regional changes of the loess microstructure are reflected in the changes of aggregate morphology and the contact mode of the framework particles.

   As for the aggregate form of the loess, in Lanzhou, Taiyuan, Datong, Jingbian, Guyuan, Zhenyuan and other region of Northwest Loess Plateau, the aggregates of the loess have sufficient rigidity, and their shapes are also rigid, and there are lots of fine crystals of calcium carbonate attached to them. However, in Henan Luoyang and Beijing yanchi of the southeast, the clay aggregates are soft and even present as flowing colloid. Microcrystalline calcium carbonate was not visible on the aggregate surface. Some aggregates have merged into a clot, and some of the cohesive particles in the aggregate have been separated from the parent body and dispersed separately in the pores or attached to the joints of the particles.
The contact method of the framework particles is mainly point contact in the loess in the northwest, and there are only few clay particles or salt crystal cements at the contact points; while the southeast is mainly surface contact, and the clay particles or salt crystal cements are thicker at the contact points.

2.5. Classification of the loess microstructure
The composition of the skeleton particles of the loess is the main body and core of the microstructure of the loess. The contact relationship between the skeleton particles affects the cementation strength of the structure, and the arrangement of the skeleton particles is closely related to the stability of the entire structure [15]. These are important basis for classification of microstructure of loess. According to the types of structures that can actually be observed in the microstructure photos of the loess, the microstructure of the loess can be classified according to the mutual relationship between the morphology, arrangement and contact of the skeleton particles. For example, the literature [14] divided the microstructure of Chinese loess into 12 categories, and the literature [15] summarized Xi'an loess into five types of microstructures.

3. CONCLUSION AND PROSPECT
Based on the previous research results, this paper summarizes the microstructure characteristics of the loess, such as the skeleton particles of the loess and the way they are connected and arranged, and the types of pores of the loess. It can be seen that the microstructure characteristics of Chinese loess change regularly with spatial distribution, which is mainly related to changes in regional climatic conditions. Studying the microstructure characteristics of loess is helpful to explain the changes in the macro-engineering properties of loess. At the same time, it also provides a basis for speculation on the formation and development of loess. At present, the research on the microstructure of the loess has gradually changed from qualitative research to quantitative analysis. At this stage, problems such as accurate extraction of microstructure parameters and dynamic observation are still needed, further research is required.

ACKNOWLEDGEMENTS
This research was funded by Shaanxi Provincial Land Engineering Construction Group Research Project (DJNY2019-22).

REFERENCES
[1] G.R. Gao, Formation and development of the structure of collapsing loess in China, Eng. Geol., 25: 235-245 (1988).
[2] L.X. Gao, J.G. Sun and L.K. Tan, Microstructure Effect on the Collapsibility of Unsaturated Loess, J. Dalian nationalities University, 66-69 (2008).
[3] C.Y. Fan, Microstructure of loess in Heifangtai and its indication of the landslide cause. Ph.D. thesis, Lanzhou University, Lanzhou, China (2010).
[4] R.S. Lin, Analysis of microstructure, porosity and water conductivity of Weibei loess, Shaanxi Water Resources, 43-47 (1990)
[5] J. Deng, L.M. Wang, Z.Z. Zhang, Microstructure characteristics and seismic subsidence of loess, Chinese Journal of Geotechnical Engineering, 542-548 (2007).
[6] W. Feng, S.Q. Li, L.X. Gao, Y. Zhan, Study on relationship between microstructure and soil-water characteristics of remolded clay, J. Guangxi University(Natural Science Edition), 38:170-175 (2013).
[7] Y.C. Zhang, F.Q. Yang, X.Y. Zhang, H.M. Liu, Microstructure of loess in collapsibility and seismic subsidence, J. Lanzhou University (Natural Sciences), 76-80 (2011).
[8] R.L. Hu, G.L. Guan, X.D. Li, L.Z. Zhang, Microstructure effect of compressive deformation of loess, Hydrogeology & Eng. Geol., 32-37 (1998).
[9] D.S. Liu, The Loess Deposits in China. Beijing: Science Press, 1-244 (1965).
[10] G.R. Gao, Microstructure of loess soil in China relative to geographic and geologic
environment. *Acta. Geo. Sinica.*, 265-272+279-280 (1984).

[11] G.R. Gao. Microstructure classification and collapsibility of loess. *Scientia Sinica*, 81-86+115-118 (1980).

[12] F.L. Ma, X.H. Bai and M. Wang, Quantitative Analysis of Loess Microstructure and Collapsibility. *The 1st Annual Conference of Civil Engineering in Central and Western China*, 417-424 (2011).

[13] X.Y. Lei, Pore characteristics of loess near Xi'an. *Hydrogeology & Engineering Geology*, 34-37+29 (1984).

[14] G.R. Gao, Microstructure of Chinese Loess. *Chinese Science Bulletin*, 35-38 (1980).

[15] X.Y. Lei, Type of the Loess microtextures in Xi’an district. *J. Northwest University*, 59-68+130-135(1983).