Research status and Prospect of initial damage of rock mass in laboratory

Cong Liu¹, Chunling Yao¹,2.*, Songyuan Zhang¹,2, Yong Cheng¹, Qi Nie¹, Zhennan Liu¹,2

¹Faculty of metallurgy and mining, Kunming Metallurgy College, Kunming 650033, China
²Kunming Key Laboratory of Comprehensive Utilization Resources of Rare and Precious Metals, Kunming 650033, China

*Corresponding author e-mail: yaochunling@kmyz.edu.cn

Abstract. Rock has experienced hundreds of millions of years of geological activities, and there must be defects of multi genesis, multi type and multi-scale, which often become the core factor limiting the function and safety of rock. In this paper, the initial damage of rock mass is taken as the research object. Based on the literature research, the development process of initial damage of rock mass in the laboratory is summarized. The scale classification, fracture preparation method and fracture observation method of initial damage are described respectively. On this basis, this paper analyzes the problems encountered in the current research of initial damage means, points out the key areas that should be paid attention to in the future, and lays a foundation for the further development of rock mechanics.

1. Foreword

The description and evolution of rock damage are mainly realized by damage variables, while the mechanical behavior of damage can be reflected by damage variables and constitutive equations. The definition of damage variable is the key problem and foundation, because the damage variable directly reflects the damage mechanism. In the sense of mechanics, one of the important principles of damage variable selection is that it is easy to establish a connection with macro mechanical quantities and easy to measure.

Based on the definition of damage mechanics, damage is defined as the deterioration of the macro mechanical properties of materials or structures caused by the irreversible change of the initiation and propagation of micro structural defects (such as microcracks, micropores, etc.) under the action of external load or environment. Damage mechanics, based on continuum mechanics and thermodynamics, is a subject to study the development of micro void or micro crack in materials and its effects on stress, strain and failure. Its research purpose is to determine the damage evolution law of materials, the mechanical behavior characteristics of materials containing damage and the mechanism of its performance degradation under load [1]. After hundreds of millions of years of geological activities, rocks inevitably have defects of multi genesis, multi type and multi-scale, and these defects often become the core factor limiting the function and safety of rocks [2]. In essence, the damage and failure of rock mass is caused by the expansion and evolution of internal microcracks and micropores...
due to the influence of external actions, that is, the microcracks and micropores in rock materials lead to the reduction of effective bearing area and bearing capacity. Therefore, the mechanical properties of rock mass are degraded [3]. Most of the initial damage of rock mass is spatially distributed, some on the surface of rock mass, some in the interior of rock mass, and the existence form of these initial damage directly affects the strength characteristics of rock mass [4-6]. However, in the process of many scholars' research, the initial damage of rock mass is ignored, which leads to the increase of the error of analysis results and the unreasonable constitutive model.

Taking the initial damage of rock damage mechanics as the research object in recent years, the author introduces its development process and research methods in China, and discusses the hot and difficult issues at present, summarizes the research results and existing problems in the field of initial damage and the key areas worthy of attention in the future, hoping to provide the basis for the further development of rock damage mechanics.

2. Study on the "scale" of initial damage

The key problem in the study of initial damage is the accuracy of initial fracture identification. The corresponding accuracy is different, and the observation method, research method and constitutive equation are also different. According to the characteristic size and research method, the initial damage can be divided into three types: macro meso micro. According to Zhang Ru [1], Yang ganshe [2], Zheng Kehong [7] and Guo Yinhua [8], the macro scale is defined as > 10^{-3}m, which belongs to the scope of engineering technology, such as joints and structural planes, which are generally processed based on empirical data. The micro scale is defined as 10^{-6} \sim 10^{-3}m, which belongs to the application force in the scope of science, the rock materials are usually assumed to be treated as continuous media; the micro scale is defined as 10^{-9} \sim 10^{-6}m spatial scale, from atom to grain, which belongs to the scope of material science.

![Figure 1. Schematic diagram of rock mass damage scale](image)

Although the scale of rock fracture in the above literature is slightly different, it can be found in the actual engineering that there are both macro fractures such as joint plane and micro fractures such as pores, micro cracks and micro bedding. Although macro cracks play a leading role in this kind of comprehensive influence which spans thousands of times, stress concentration often occurs at the defect location, thus affecting the macro mechanical properties of rock. In the past experiments, scientists mainly focused on the research of macro fractures, and made gratifying progress. But in recent years, the impact of micro fractures on rock mass has also been paid attention by scientists, such as: freeze-thaw damage, creep damage, cyclic load damage, blasting load damage, impact fatigue, acid-base corrosion damage, etc.

In the study of micro cracks, it mainly refers to the defects of materials at the molecular and atomic scales. According to academician Xie Heping [9], the brittle fracture of rock is mainly intergranular
fracture and transgranular fracture (or the combination of the two). The objects of concern should include the combination of molecular bonds, the thermal fluctuation, diffusion, dislocation, slip, plastic flow of atoms, etc. The corresponding micro damage research methods are mostly quantum mechanics, statistical mechanics and other methods [2]. However, because the theory has not been systematized yet, and the calculation of statistical mechanics is too large, scholars mainly focus on qualitative analysis of damage, while quantitative analysis of micro cracks is rarely studied.

3. Initial damage crack preparation

The physical and mechanical properties of rock are the prerequisite for us to understand and study rock and its deformation and failure laws. Compared with large-scale in-situ testing, many scholars are committed to small-scale laboratory rock mechanics experiments, aiming to study the mechanical properties of a rock from the most simple methods, the most convenient experimental conditions, the lowest cost, and the specific conditions to find the rock force. The parameters and the law of fracture propagation and evolution are used to guide the field practice. At present, for the acquisition of rock samples, one is field sampling, but there are four problems: 1. High discreteness of rock samples; 2. Opacity of natural rock samples; 3. It is difficult to obtain rock samples of the same size in the same direction that meet the requirements when studying anisotropy; 4. It is difficult to acquire some rock samples; the second is Mold pouring, there are three problems: 1. Bubbles and sedimentation will occur in the sample preparation process; 2. A certain Some fine size samples can not meet the accuracy requirements; 3. Some rock samples are difficult to obtain by pouring [10].

The key to making rock samples with initial damage is to make and embed cracks. However, the rock samples made by the method of prefabricated fracture can only make macro scale fracture, and the fracture propagation law is also from the macro scale fracture propagation law. Although it can reflect the basic characteristics and mechanism of rock fracture propagation and fracture to a certain extent, it is obviously different from the damage form and propagation law of rock with macro fine micro fracture in the real world. This method exists In the obvious shortage.

Many scholars use the method of preloading to obtain the initial damage, although it can reflect the characteristics of the initial damage to a certain extent, but in the process of preloading, a part of the original micro cracks have already expanded and penetrated, and suffered serious damage, which will produce damage local effect. It is because of the complexity of the law of fracture propagation and evolution in natural rock mass that the error of experimental results becomes larger and the dispersion is higher. Therefore, many scholars hope to use similar simulation materials to solve the above problems. However, the traditional method of artificial production of experimental samples can only be used to make macro joint cracks, micro or complex structure samples (such as S-type cracks) or internal defect samples are very difficult to make, and can only be studied by numerical simulation. Therefore, the preparation of rock samples with high efficiency, high reduction degree and high precision is the key to the experimental research of rock mechanics in laboratory, and it is also the field that many scholars are studying and breaking through in recent years.

In view of the shortcomings of the above two main prefabricated cracks, many scholars combined 3D printing (3DP) technology to prefabricate the rock with initial damage for research, such as a method based on CT scanning and 3D printing applied by Chang’an University to make the internal structure of rock mass. At present, the principle of 3D printing can be divided into three types: SLA, LOM, SLS, FDM, 3DP and DLP. Among them, SLA, LOM, SLS and FDM are the current mainstream of 3D printing. In terms of the production of rock like samples, SLA, FDM, SLM and 3DP are the main materials. Gypsum, plastic, polyester and resin are the printing materials, but these materials have not completely solved the limitations of low strength and high plasticity. Moreover, the fracture accuracy of 3D printer is still at 0.2mm level, which can not meet the research of micro initial damage in rock mechanics experiment. Rock is a mixture of a variety of rock forming minerals. The mixing mode of minerals will greatly affect the mechanical properties of rock and the law of fracture expansion and evolution. However, today's 3D printer can't do the mixing printing of rock. For example, the uniaxial compressive strength of powder gypsum is generally less than 10MPa.
Moreover, the existing 3D printer cannot satisfy the printing of large and complex models (the maximum printing size of ProJet ® X60 series printer is 508mm × 381mm × 229mm). However, 3D printing technology will undoubtedly have a great influence on the study of the mechanical properties of rock mass for the two functions of the fracture replication structure and the customized structure in the initial damage of rock mass.

From macro fracture making, rock damage preloading, to the application of 3D printing technology in rock mechanics experiments, scholars are working hard for real reduction rock samples. In the research of initial damage of rock, the future development direction must be the combination of non-destructive cross-scale detection technology such as CT scanning and 3D printing technology, which will inevitably make rock mechanics experiment rise to a new height.

4. Initial damage fracture observation method
As mentioned before, the initial damage is actually the proportion of the original rock initial fracture, but the initial damage fracture span of rock mass is large. In order to further study the initial damage fracture, scientists have developed from optical microscope to scanning electron microscope, from two-dimensional to three-dimensional, from single-scale identification to cross-scale identification, which is not only helpful for understanding the damage mechanism of rock mass, but also for the later multi-scale identification The construction of damage model provides important basic conditions. CT scanning technology is widely used in the field of initial damage research of coal and rock because of its advantages of no damage, high resolution and digitization.

CT scanning technology has been proved to be an effective tool for rock damage detection. It not only makes it possible to observe the micro cracks in the rock under arbitrary stress, but also fills in the blank of the observation of the crack evolution process from the conventional SEM scale to the macroscopic scale visible to the naked eye. More importantly, the observation results of CT can be more directly related to the stress-strain curve of the rock specimen, which can be used to deduce the constitutive relationship and damage evolution equation of the rock. CT scanning has so many advantages, all of which are based on high quality images. At present, limited by space-time resolution, image reconstruction algorithm, noise and other factors, the acquisition of high-quality CT images is relatively difficult, so there are still many problems to be solved in the establishment of damage constitutive relationship based on CT scanning.

5. Conclusion
The coupling mechanism of rock with initial macro and micro defects in stress environment is not clear. The response law of the development degree of rock fracture to the strength characteristics of rock is different, so it is very important to define the initial macro and micro damage of rock accurately. Therefore, the cross-scale research of initial damage fracture must be the most important in the future damage mechanics.

3D printing overcomes the difficulty that the traditional sample preparation method can't make complex fracture model. Combined with CT scanning technology, it can more truly restore the model of rock mass with initial damage fracture, but the printing material instead of rock is still the bottleneck of research.

With the development of CT scanning technology, the gap between SEM and macro fracture is filled up, which makes it possible to span macro fine micro scale. It is more convenient to study the fracture propagation law of cross scale rock mass with initial damage and establish a more accurate cross scale constitutive model. However, it is difficult to coordinate the speed, resolution and image reconstruction algorithm of CT scanning, and the precise location of small pore failure and the law of damage location expansion and evolution in the process of rock mass experiment still cannot achieve satisfactory results. However, the advantages of CT scanning have been paid more and more attention by scientists. In the future, with the development of holographic technology, the three-dimensional evolution model of rock mass with initial damage fracture and the real-time visual observation of the internal fracture expansion law are just around the corner.
Acknowledgments
This work was financially supported by Scientific Research Foundation Project of Yunnan Education Department: Multiscale Fractal Analysis of Unloading Fracture Propagation Law of Damaged Rock Mass (2019J0891) fund.

References
[1] Zhang Ru, et al. Basic theory and experimental study of rock acoustic emission [M]. Sichuan University Press,2018,8.
[2] YANG Gengshe, SHEN Yanjun, JIA Hailiang, et al. Research progress and tendency in characteristics of multi-scale damage mechanics of rock under freezing-thawing [J].Chinese Journal of Rock Mechanics and Engineering,2018,37 (3):31-49.
[3] Zhang Quansheng, Yang Gengshe, Gao Guangyun, Pu Yibin. Review on Application of X-Ray Computerized Tomography (CT) to Rock Damage Measurement [J]. Mechanics and Practice,2005 (06):11-19.
[4] Zhang Zhigang, Qiao Chunsheng, Li Xiao. Experimental Study on the Strength of Single Joint Rock Mass [J]. China Railway Science,2007,28 (4):34-39.
[5] Liu Yuanming, Xia Caichu, Li Hongzhe. Development in Joints Research and Its Application to Rock Mass Containing Discontinuous Joints [J]. Chinese Journal of Underground Space and Engineering,2007,3 (4):683-687.
[6] LI Hongzhe, XIA Caichu, WANG Xiaodong, et al. Experimental Study on Deformation and Strength Properties of Jointed Marble Specimens [J]. Chinese Journal of Rock Mechanics and Engineering,2008,27 (10):2118-2123.
[7] Zheng Kehong. Study on Mesostructure and Damage Characteristics for Coal and Gangue Particles based on X-Ray CT [D]. China University of Mining and Technology,2016.
[8] Guo Yunhua. A Statistical Damage Model of Rock Failure and Fractured Rock Mass Gradual Damage Numerical Simulation[D]. Shandong University,2014.
[9] Xie Heping. Study on fractal model of marble micro fracture [J]. Chinese Science Bulletin,1989 (05):365-368.
[10] Hua Minjie. Preliminary Study on the Application of 3D Printing Technology in the Specimen Preparation of Rock Mechanics. [D]. Nanjing University,2015.