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Microstructures and Physical Properties Characterisation of Rocks Using Multi-Analytical Techniques

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Abstract: This study aims to characterise the effect of wet-dry cycles on microstructures and physical properties of rocks. Utilising techniques like Scanning Electron Microscopy, Electron Probe Microanalysis, petrographic analysis, changes in microstructure have been thoroughly observed. Rocks were subjected to controlled wet-dry cycles, stimulating long-term weathering to resemble the natural environmental conditions. Results from porosity analysis revealed a direct relationship to weathering of rock. Correlating the results from clay content determination through X-Ray Diffraction Analysis analysis showed that rocks comprising higher clay weather quickly when they come into contact with water. Microstructural analysis demonstrated the intensification of microcracks and micropores, along with the discolouration of minerals. Correlating the results from both mineralogical and microstructural analysis, significant effects of the wet-dry cycle have been identified that clearly show the degradation of rock integrity with repetitive moisture fluctuations. This combined approach highlights the impacts of seasonal variations in microstructural and mineralogical parameters emphasising the necessity to incorporate the parameters in slope stability assessments.

Keywords: ***Wet-dry cycles, Rock microstructures, Micro-analytical techniques, Slope stability.***

Introduction

Slope instability has become one of the serious global issues causing loss of life, economic damage, and long-term disruption to localities as well as infrastructure. Stability of the slope is influenced by several factors such as the mechanical properties of rocks, the presence of discontinuities, and environmental stresses such as rainfall, temperature, seismic activity, and weathering cycles. Microstructures (small-scale structures in rocks) such as microcracks, micropores, and microfractures also play a major role in determining their mechanical properties. Wet-dry cycles simulate a realistic environment for long-term weathering that creates stress in rocks. This leads to the formation and development of microstructures that ultimately reduce the rock mass strength. The detailed analysis of these microstructures provides valuable insights into the prediction of rock behaviour under mechanical stress (Vales et al., 1999) such as rainfall, seismic activity, and weathering cycles. Detailed analysis of these structures helps to know the deformation mechanisms, which is very important in knowing about the stability condition of the slope.

This research focuses on a comprehensive analysis of the physical properties and microstructural characterisation of rocks relating to slope stability. Examining how cyclic weathering affects rock integrity by utilising different technical methods and analytics techniques such as Scanning Electron Microscopy (SEM), reflection photography, petrographic analysis, X-Ray Diffraction (XRD) analysis and Electron Probe Microanalysis (EPMA), this study aims to enhance the understanding of rock response under different environmental conditions

Methodology

Samples obtained from the unstable area within Oda City and Izumo City have been cut, trimmed and smoothed as per the requirements of several tests. The original samples were used for making the powder required for the specific gravity test method (Japanese Geological Society 0111), XRD analysis and clay content determination. The processed samples were utilised for wet-dry cycles where they were kept in a desiccator at a constant pressure of 0.1 MPa till a constant weight was achieved, followed by drying of the sample at 105℃ till a constant weight was achieved. XRD analysis was performed over a 2θ range between 5° to 70 A°, with measurements taken every interval of 0.02° and a scanning speed of 10° per minute. Similarly, diffractograms in the 2θ range between 2° to 40 A° at an interval of 0.02° and a scanning speed of 3° per minute were obtained for clay content determination. Thin sections of different rock samples were prepared for petrographic analysis and EPMA for microstructure analysis. Similarly, rock samples less than 3 cm in width and 1cm in height were prepared for SEM analysis and reflection photography analysis.

High-resolution images that were obtained from SEM analysis performed in each cycle were used to monitor the change in the microstructures. Diffractogram obtained from XRD was analysed through X'Pert HighScore Plus software for mineral identification, and RockJock software was utilised to identify and quantify the clay content.

Results and discussions

The study demonstrated the progressive weight loss in all rock samples while the rate of weight loss varied among the rock types. Sandstone, mudstone, conglomerate and tuff showed a high rate of weight loss as compared to andesite, rhyolite and basalt with very minor change in weight. The results depicted the presence of a higher percentage of smectite (a well-known swelling clay) which showed quicker disintegration than samples that comprise a higher percentage of quartz and feldspar (rhyolite, basalt and andesite) showed greater durability. These smectite and vermiculite observed in the samples undergo expansion and contraction with the fluctuation of water (Hossain et al., 2025).

Figure 1 shows increased saturation and drying time with the number of wet-dry cycles depicted by andesite. This was caused by sensitive minerals like illite, muscovite, smectite and vermiculite causing breakdown of the pores into many micropores which in turn increases the tortuosity of the flow (Zuo et al., 2016).

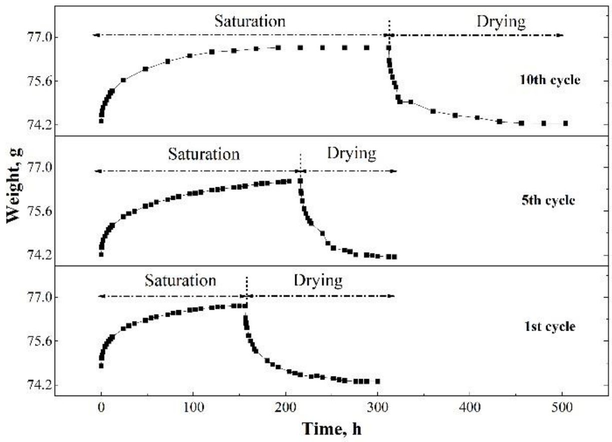

Figure 1, Increase in saturation and drying time (andesite)

The results demonstrate the increase in porosity with the increasing number of wet-dry cycles, as indicated by overall decrease in weight. This increase in porosity affects the microscopic mechanical properties of rock which is closely related to the weakening process of rock (Yang et al., 2019) ultimately affecting the stability condition of slope.

Microstructural degradation such as micropore enlargement, intensification of microcracks, and detachment of grain boundaries was confirmed through thin section, SEM, and EPMA analysis which eventually decreases the strength of the rock mass (Figure 2).

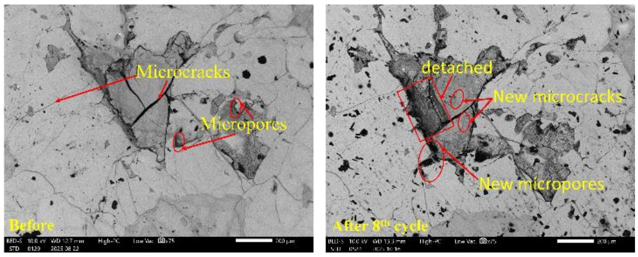

Figure 2, BSE images of andesite 2 (a) before wet-dry cycle; and (b) after 10th wet-dry cycle.

Conclusions

The findings revealed that repeated wet-dry cycle causes the clay-rich rocks to disintegrate rapidly and increase in porosity. Microscopic weakening observed before and after wet-dry cycles such as microcrack intensification, pore enlargement, and grain boundary detachment through several microscopic observations revealed the increase of these changes with increasing number of cycles. Overall, the findings indicate that the role of mineralogical composition (specially clay content) governs the rate of weathering, porosity evolution and mechanical weakening that critically influences long-term slope stability.

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