STUDY ON COVER SYSTEM AND REVEGETATION METHOD FOR THE PREVENTION OF ACID MINE DRAINAGE IN OPEN-PIT COAL MINE IN INDONESIA

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出版情報：九州大学, 2016, 博士（工学）, 課程博士
バージョン：

（様式 2）

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論 文 名　：STUDY ON COVER SYSTEM AND REVEGETATION METHOD FOR THE PREVENTION OF ACID MINE DRAINAGE IN OPEN-PIT COAL MINE IN INDONESIA
(インドネシアの露天掘り石炭鉱山における
酸性坑廃水の抑制を目的とした覆土および再緑化工法に関する研究)

区　　分　：甲

論　文　内　容　の　要　旨

Acid Mine Drainage (AMD) is a serious environmental problem in coal mines in Indonesia, resulting from the dissolution of sulfides through the exposure to oxygen and water in consequence of excavation of overburden and coal. The coal production in Indonesia can be expanded, or at least it is never going to significantly decline in the future, and thus contributing to further formation of AMD. Although many open-pit coal mines in Indonesia have been engaged on the construction of Net Acid Generation (NAG) cover system for prevention of AMD, the current condition of the system was evaluated in a few studies. Additionally, problems in the system have been recently reported; therefore, this study aims to elucidate the problems in NAG cover system, and to establish a novel system in consideration of the problems.

Chapter 1 introduced the coal mining in Indonesia and the countermeasures against AMD, followed by the purpose of this study.

In chapter 2, as a first step, the current condition of a waste dump was investigated in order to understand the problems in NAG cover system through the sample analysis and field observation. In the research area, AMD occurred in the waste dump as a consequence of the influx of oxygen and water into the layer consisting of Potentially Acid Forming (PAF) at 50-70 cm depth through the surface layer, in which the degrees of saturation was ca. 73-75%. Furthermore, three main problems were revealed in this chapter through the field observation. The shortage of Non-Acid Forming (NAF) resulted in the placement of PAF in the surface layer of the waste dump, leading to the occurrence of AMD: More than 50% of waste rocks consisted of the cause of AMD. In addition, the exposure of PAF to oxygen as the result of the failure of a cover layer contributed to an acceleration of the occurrence of AMD. Finally, the formation of AMD in the waste dump led not only to the contamination of water but also to the death of plants and the acceleration of AMD along with surface erosion of the waste dump. These problems were considered cross-cutting issues associated with cover system, including geochemical, physical, and botanical perspectives. The issues have to be resolved in terms of not only the prevention of AMD but also whole process of mining operation, including the classification of a waste rock, the construction of a waste dump, and rehabilitation program.

In chapter 3, with respect to the issue of the shortage of NAF, PAF with low acid producing potential were tried to utilize for a cover layer through the reassessment of the evaluation of acid producing potential of waste rock and the current method of the classification in open-pit coal mine in Indonesia, by performing the 3 types of a column leaching test. Acid producing potential estimated based on the form of sulfur played an important role in the selectin of cover materials and the placement of them in cover system, and likewise the change of hydraulic conductivity of a cover layer with rock weathering was also important in terms of the performance of a cover layer to mitigate the oxidation of PAF. Hence, based on the results of the leaching

test and the sample analysis, novel classification method of waste rocks was proposed in terms of the occurrence of AMD for a long time by considering Net Acid Producing Potential (NAPP), NAG pH, and the results of sequential NAG test. This method can classify PAF which has been treated as the source of AMD into Low PAF (LP), Low NAF (LN), and Middle-Potential PAF (MP-PAF). Moreover, it was indicated that the amount of NAF, which is generally used for a cover layer, can be reduced by using Low PAF (LP1) for a sub-layer of the multi-cover system in the mixing method at the mixing ratio of 20%, but it was difficult to utilize the rocks with high NAPP and low proportion of sulfides for a sub-layer. The rocks which were not suitable for a sub-layer can have been separated by the proposed classification method.

In chapter 4, the mechanism of the failure of a cover layer was elucidated in terms of three perspectives: Rock weathering, strength reduction, soil erosion under acid conditions. In regard to the weathering of rocks, physical and chemical weathering mutually accelerated through the slaking and the dissolution of soluble minerals with the formation of AMD during the wetting and drying cycle in the argillaceous rocks, containing sulfides and clay minerals related to slaking. This was proposed as the mechanism of the interrelation among chemical and physical weathering of rocks, and the occurrence of AMD. For the prevention of failure of a cover layer by the decrease of the strength of rocks and soils with acidification, PAF is recommended to be kept away from the slope more than 4 m, and several lifts should be constructed by lifting up in a waste dump in addition to the 1 m of the cover layer composed of a sub-layer and NAF layer. The sub-layer is, furthermore, formed with scraper above PAF, followed by the construction of NAF layer after the forced weathering of sub-layer, which allows waste rocks to form less than 1.0×10^{-8} m/s of low permeable layer on the waste dump. However, compaction characteristics of rocks were deteriorated owing to the change of montmorillonite to kaolinite with acid production during the weathering process, resulting in the reduction of Young’s modulus over time. The LP, LN, and MP PAF which are thought to be utilized for a sub-layer in the multi-cover system can form a low-permeable layer due to weathering of rocks in the forced weathering process without the deterioration of compaction rate since H^+ is not continually produced. Additionally, it was revealed that soil erosion was accelerated by the decrease of plasticity index caused by the aggregation by Al^{3+} at pH ranging from 2.0 to 6.0.

In chapter 5, finally, the effect of AMD on plant growth in rehabilitation was investigated in addition to the laboratory plant experiment with the establishment of new guideline of rehabilitation in consideration of the effects. It was revealed that the dissolution of Al and acid conditions influenced the growth of plants in the waste dump. In addition, it is necessary to introduce a new evaluation method of soil conditions in consideration of the lag time of dissolution of sulfur from waste rocks and soils in a waste dump for effective revegetation. The concentration of Al should also be included in the regulation in conjunction with the monitoring works on the concentration of dissolved Al in a waste dump with the aim of achieving successful rehabilitation in mining operation. Furthermore, the plants with very high Al tolerant, such as *Melaleuca leucadendra* and *Melastoma malabathricum*, should be preferentially selected in the primary revegetation for the improvement of soil conditions. The plant cover on the surface of a waste dump led to the reduction of the influx of water and oxygen at the rate of 12.3% and 13.0% at 1 m depth, respectively. On the basis of the results, new guideline of rehabilitation program in consideration of the construction of the multi-cover system was established in this chapter. Successful rehabilitation can contribute to not only the environmental conservation but also the prevention of the influx of oxygen and water into a waste dump in addition to the stability control of a cover layer, resulting in prevention of AMD.

Chapter 6 concluded this study by summarizing the results in all of the chapters.