論　文　要　旨

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論文題名　Study on the acid mine drainage generation at coal mine overburden dumps in Indonesia and its control system using fly ash
(インドネシアの石炭鉱山での捨石集積場における酸性坑廃水の生成とフライアッシュによる抑制に関する研究)

論　文　内　容　の　要　旨

The demand of coal as one of the important resources in Indonesia, both as the export commodities and the national energy source, has been increasing. In 2010, Indonesia produced 275 million tons of coal, of which 218 million tons were for export and 57 million tons were for domestic consumption; mostly used for electric power generation. Since the proportion of coal among electricity generation sources in Indonesia in 2025 is expected to be 33%, the production capacity is likely to continue to increase. This is projected to increase the fly ash as a combustion by-product, which provides another issue in relation to the ash management as waste.

Acid mine drainage (AMD), the result of sulfide oxidation in the absence of alkali minerals to neutralize, is commonly found in coal mine areas since pyrite exists in coal formations. AMD potentially occurs in many points of mine site, such as pit faces, roads, overburden dumps, reject coal dumps and coal stock piles. However, considering the fact that overburden dumps are the place in which the ready oxidized sulfide-minerals containing rocks are stored for a long time, more care should be paid in those areas in an attempt to mitigate AMD generation. At the dumping site, the AMD generation mechanism is complex since both physical and geochemical processes cannot be considered separately, and are very dependent on site-specific conditions. Those conditions lead to specific approaches and design purposes of the dry cover system which should consider some specific conditions, such as availability of materials, local environmental characteristics, and mining operations, to achieve the optimum performance of controlling AMD.

This dissertation describes and discusses the characteristics of overburden dump related to the AMD generation potential and the utilization of site-specific fly ash to inhibit the AMD generation in overburden dumps, consisting of seven chapters as follows:

Chapter 1 introduces the background of studies including the AMD generation process within overburden dumps, dry cover systems, and objectives of the study, which involves the outline of the dissertation.

Chapter 2 discusses the characteristics of overburden rocks in Indonesian coal mine sites, particularly those related to the AMD generation potential, spatial distribution and the influence of mining operation.

Chapter 3 describes the characteristics of the formed-internal structure of coal mine overburden dumps, and mainly focuses on the physical and geochemical conditions related to the AMD generation mechanism. It was found that the dump is comprised of several bench lifts, which are bound by a natural morphologic surface, such as a low-wall slope along which the material is deposited, developing an angle of repose face and a traffic surface at the top of each lift. Gravity variation occurs along the mixed inter-fingered inclined layer due to the end dumping technique. Hydraulic conductivity and groundwater flow of the inner dumps is controlled by the combination of physical and chemical weathering. Moreover, a multi-compacted layer combined with alternating inclined layers, and in concordant with the absence of the coarse basal layer, has limits for the air diffusion or convection into the overburden dump body. The geochemical characteristics which alternate randomly among potentially acid forming (PAF) and non acid forming (NAF) materials within the inter-fingered layer may control the acidification-neutralization reaction of infiltrated water, secondary mineral precipitation and subsequently the quality of the overburden dump drainage. Considering both the physical and

geochemical formed-internal characteristics, albeit a self-developing acid drainage inhibition system may occur in the long-term, further study regarding either single or multiple layers with various geochemical characteristics and conditions is needed to comprehend the AMD generation and release observed in such specific conditions.

Chapter 4 describes the investigation on AMD release behavior of sulfide minerals containing rocks due to different water pouring intervals and some layering scenarios of PAF and NAF rock have been carried out using column leach test. It was confirmed that water played an important role concerning the AMD generation and release from sulfide weathering in the rock system which influences the physical-hydraulic properties as well as its role as a reactant and contaminant carrier. A condition where the degree of water saturation is stable at very low (<10%) or very high (>80%) promotes the slowest reaction rate of oxidation. In general, inherent geochemical properties of the rock determined the quality of the leachate. However, under the actual climatic conditions, an interrelationship between physical conditions and geochemical reaction rate which occurs within the material system played an important role in determining the quality of the leachate. Furthermore, the experiment of a multi-layer material showed that the presence of NAF rock in the column affects the whole system in the column, both geochemically and physically. Generally, the addition of NAF rock increases the availability of alkalinity in the system to neutralize the generated acid and reduced the oxygen supply when it is applied to cover the sulfidic rock layer. Hence, this kind of approach should be considered in developing an acid generation prevention system.

Chapter 5 describes the laboratory scale and field scale column tests which were carried out to investigate the effect of site-specific fly ash addition on the AMD generation characteristic of the fly ash-coal overburden rock co-placement, either in the mixture or layering scenario. The addition of fly ash increased the neutralizing capacity of the mixture; hence it promotes the capacity to buffer acid. With the increase of buffering capacity within the mixture, the sulfide oxidation product can be balanced to produce the near neutral leachate. This condition may commence the precipitation of iron hydroxide throughout the experiment which may coat the reactive surface and inhibit further oxidation reaction. The concentration of some dissolved metals in the leachate of each fly ash composition remained lower than the regulation threshold. The oxygen concentration below the multi-layer of NAF rock and fly ash layer was lower than that of NAF rock alone in the field scale column test, which indicates the potential of the fly ash layer as an oxygen barrier layer. The calculated oxygen diffusion coefficient of oxygen in fly ash layer was 1.6×10^{-7} m^2s^{-1}, about one order of magnitude lower than that of the NAF rock layer. Hence, the application of a fly ash layer as part of a cover layer in the overburden dump seems interesting to be implemented.

Chapter 6 describes a comprehensive physical characterization and the compaction of fly ash and fly ash-overburden rock mixture (FA-mix) which were performed from the stand point of utilizing the fly ash for mine overburden management. Due to the non-cohesive properties of fly ash, the mixing scenario with over-burden rock was chosen in order to maintain the plasticity properties of cover layer meet the requirement of geotechnical integrity. Physically, fly ash has a low specific gravity of 1.2, and is mostly constituted of sand size particles (>95%). The addition of fly ash in the mixture affects on the increase of the plastic limit (16–25.5%), which hence results in decreasing the plasticity index (20.4–8.4%) afterward. Moreover, the dry density of the compacted mixtures was decreased by 15% for each 10% addition of fly ash in the mixture, whereas the optimum moisture content was increased by 35%. The addition of fly ash in the mixture increases the hydraulic conductivity, porosity and the oxygen diffusion coefficient. The experiment results show that the maximum addition of fly ash in the mixture is 10% in which meets the recommended plasticity properties and performance for the dry cover purpose. Furthermore, evaluation on the proposed cover system using a FA-mix layer indicated an improvement of the performance of the cover system in oxygen diffusion prevention, in addition to the potential of a higher pH of percolated water, thus may significantly reduce the require thickness of NAF layer to achieve a similar oxygen diffusion coefficient compared to the current practice of cover systems. Moreover, the proposed cover system may become an alternative for dealing with fly ash utilization than conserving as waste.

Chapter 7 summarizes the conclusions of this study and recommendations for further study.