Numerical Simulation on Self-heating Behavior of Coal Piles Considering Aging Effect in Exothermic Oxidation

張, 河猛

https://hdl.handle.net/2324/4110504

出版情報：Kyushu University, 2020, 博士（工学）, 課程博士
バージョン：

（様式２）

氏　　名　：　張　河猛　(Zhang Hemeng)

論 文 名　：　Numerical Simulation on Self-heating Behavior of Coal Piles Considering Aging Effect in Exothermic Oxidation (酸化発熱における時間減衰効果を考慮した石炭パイルの自己発熱挙動に関する数値シミュレーション)

区　　分　：甲

論 文 内 容 の 要 旨

The usage of low-rank coals in steel makings is increasing with decreasing high rank coals in the world. Spontaneous combustion of coal piles and seams leads to environmental hazards and economic losses, and it has been recognized as one of sources of greenhouse gases (GHG) emission contributing to global warming and climate changes. It is required to reduce CO_2 emissions by controlling and extinguishing coal spontaneous combustions by clearing the process of exothermic oxidation and self-ignition of coals under various coal pile and environmental conditions. The Arrhenius equation has been widely used as a typical and traditional model to simulate the spontaneous combustion process leading to self-ignition of coals, while it does not be able to express the aging effect on the coal exothermic oxidation leading to a status without any reaction. To develop preventing and extinguish operations for spontaneous combustions in coal piles, a reasonable exothermic oxidation model including the aging effect for spontaneous combustion of coals has been required especially in low temperature range.

This study has investigated a new heat generation model considering the aging effect using the equivalent oxidation exposure time (EOE-time) theory and decay constant to carry out numerical simulations on spontaneous combustion process of coal stockpiles. Moreover, it has been presented that a complex chemical water solution wetting the low rank coal is able to inhibit the oxidation with shifting the critical self-ignition temperature to higher temperature side compared with ones wetted by water based on the wire-mesh basket test (WMB test).

This dissertation consists of 5 chapters as follows;

Chapter 1: This chapter introduces the hazards and troubles induced by coal spontaneous combustions in the world, mechanism and major factors leading to self-ignition of coals. Furthermore, the total amount of GHG emissions from spontaneous combustions and uncontrolled coal-fires is estimated to be 0.69 to 1.2 % of annual global GHG emissions from all industrial sectors in the world. The previous laboratory and field-scale measurement results and some potential indexes on the spontaneous combustion of coals are discussed and compared. Besides, previous numerical simulation approaches are introduced, and the reason why the numerical simulations using by the Arrhenius equation has failed to simulate the subcritical temperature-time process without self-ignition is discussed and explained.

Chapter 2: This chapter focuses on the measurement results by WMB test using the low rank coal (lignite) excavated in the Inner Mongolia, China. The coal particles crushed into particles of 8 to 12 mm in size (average d =10 mm) were packed in the baskets in four sizes (L= 5, 10, 15 and 25 cm) to form cubic coal-piles for WMB tests. The thermal behaviors of the coal piles in the rising temperature process were measured against the ambient air temperature, T_e that is kept as a constant temperature during the WMB test. The critical self-ignition temperature (CSIT), critical lead time (CLT), and activation energy were evaluated based on WMB tests. With increasing the basket size, L, CSIT was dropped from 132.5 to 87.5 °C, while CLT became longer from 4.3 to 150 h, respectively. The CSIT of dried lignite coal particles was at least 10 °C lower than that of raw one.

Furthermore, effects of wetting the coal particles with the complex chemical solution of Na_2SiO_3 (2 to 20 wt%) and polyvinyl alcohol (PVA) (0.1 to 0.5 wt%) were investigated using the WMB tests. The complex chemical solutions wetting the coal particle surface generate a cross-linked gel (named SC/PVA gel) by the chemical reaction with CO_2 gas in air and emitted from heated coal particles. For the case of the cubic coal stockpiles wetted by the complex chemical solution of 16 wt% Na_2SiO_3 and 0.2 wt% PVA, its CSIT is 12.5 °C higher than that packing with raw coal particles. It shows that the developed complex chemical solution has a potential to inhibit oxidation and spontaneous combustion of coals by forming strong and stable gel on the coal particle surface.

Chapter 3: This chapter presents the numerical simulation model on spontaneous combustion of coals considering the aging effect of exothermic oxidation expressed by the equivalent oxidation exposure time (EOE-time) theory and decay constant γ. The aging model has been applied to 3-D numerical simulations of cubic coal piles in the WMB baskets using ANSYS FLUENT. The practical range of γ= 10^{-6} to 10^{-5} s^{-1} has been determined based on the matching simulations for the temperature-time curves obtained by WMB tests with 4 sizes of baskets. The larger value of γ results in lower CSIT and higher CLT. It is concluded that the developed heat generation model using the EOE-time theory and the decay constant can simulate both of the supercritical and subcritical temperature-time curves, CSIT and CLT measured by WMB tests using the cubic coal-piles with different volumes. In addition, the relationship between increase of CSIT by wetting with the complex chemical solution as described in Chapter 2 and increasing of γ was derived, and it shows that a safety operation on a field scale coal stockpile by wetting coal particles with the complex chemical solution can be evaluated by the numerical simulation model presented.

Chapter 4: This chapter presents the numerical simulation results by applying the developed heat generation of coal considering the aging effect for coal spontaneous-combustion behaviors in typical coal stockpiles set on the surface under wind. The 2-D trapezoid coal-stockpiles with bottom width w = 5 to 30 m and height h = 0.33w were simulated to investigate the effects of wind velocity υ = 0 to 14 m/s, coal particle size d = 0.3 to 10 mm and porosity n = 0.1 to 0.6 on the self-heating behavior in the stockpiles. The critical decay constant, γ_c for a typical condition of the pile (w = 15 m, h = 5 m, d = 3 mm, υ = 2 m/s and n = 0.33) was estimated to be γ_c = 1.25×10^{-6} s^{-1}. The value of γ_c is increasing with the stockpile volume that has larger effects on the self-heating behavior than other parameters. Furthermore, the sensitivity studies of each physical parameters on the value of γ_c decides CSIT. It can be summarized that the coal stockpile can keep safety on coal self-ignitions when the measured γ of the coal particles consists a stockpile is larger than γ_c that can be estimated from the numerical simulation results. The wetting operation on the stockpile using the complex chemical solution can be expected to increase γ than γ_c with shifting into a safety coal stock.

Chapter 5: This chapter summarizes the conclusions and discusses future work on spontaneous combustion of low rank coals.