Technical Report

UDC 669 . 184 . 28

Development of Steam-aging Process for Steel Slag

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Abstract

In Japan steel slag is mainly used for road construction and civil works. And the ratio of steel slag used for road construction is about 30%. Steel slag needs aging treatment before used for road construction because it has expansive nature due to the hydration of free CaO. Steam aging method and pressurized steam aging method were developed in 1990's. And these methods can shorten aging time dramatically compared with air aging (open-air storage). This paper introduces the development of steam aging method and pressurized steam aging method.

1. Introduction

In the 1990s, environmental problems garnered serious global concern, and in October 1991, a law pertaining to the utilization of recycled resource (Waste Management and Public Cleansing Law) was enacted. Under this Law, slag produced secondarily in the iron and steel making process was designated as one of the by-products, and the development of its usage and improvements in quality were obligated. As for the effective utilization of iron and steel slag, various studies have been conducted, and consequently, the rate of water-granulation of blast furnace slag was enhanced and the entire slag is effectively utilized. When compared with the case of blast furnace slag, effective utilization rate of steel slag was not so high due to the problem of expansion caused by free lime and so on.

At present, steel slag is primarily used as road bed material and civil construction material, and 30% of steel slag is used as road bed material. Expansion characteristic is a big problem when steel slag is used as road bed material. It is a phenomenon where the free lime contained in steel slag, although in a very small quantity, reacts with water and forms calcium hydroxide, its volume becoming approximately twice its original size. As a method to promote the expansion of free lime in advance and thereby suppressing expansion of steel slag, aging by leaving in natural state (hereafter called as air aging) was applied before the 1990s. However, as the air aging treatment takes 6 months or longer and, therefore large space is needed, aging acceleration (steam aging and pressurized steam aging) was developed and put into practical operation in the 1990s.

This paper introduces the steam aging method developed and put into practical operation in the early 1990s in the then Kokura Works, and the pressurized steam aging method that started practical operation in 1995 in Wakayama Works.

2. Development of Steam Aging Method and Application to Practicable Equipment

First, development and application to practicable equipment of the steam aging method that was performed in Kokura Works in the early 1990s is introduced.[1, 2)]

2.1 Study on aging acceleration method

The focal points of this development was that under the atmospheric pressure and the existence of water, the hydration rate of free lime in steel slag increases with the ambient temperature and reacts to water in short time. Then, a method of accelerating aging using steam and hot water was first studied. **Figure 1** shows a result of an experiment about how the amount of expansion (hereafter called as expansion stability ratio) of steel slag changes in the case of steel slag crushed to below 25 mm in size being held for a certain duration under the steamy atmosphere at the ambient temperature of 50°C, 75°C and 100°C.

As a result, it was found that slag becomes stabilized in shorter periods of time when the ambient temperature is higher and that highest expansion stability could be obtained in 48 h when steam in particular is used. Then, to obtain high expansion stability, it was judged that the aging acceleration method using steam, which stably provides high temperature, and the convenience in operation is excellent, and the development of steam aging method was commenced.

2.2 Result of experiment obtained with steam aging test machine

Steel slag expansion characteristics greatly vary depending on the content of free lime. Samples of steel slag were steam-aging-treated with a steam aging test machine capable of handling maximum 150 kg at a time and its expansion stability ratio after water-

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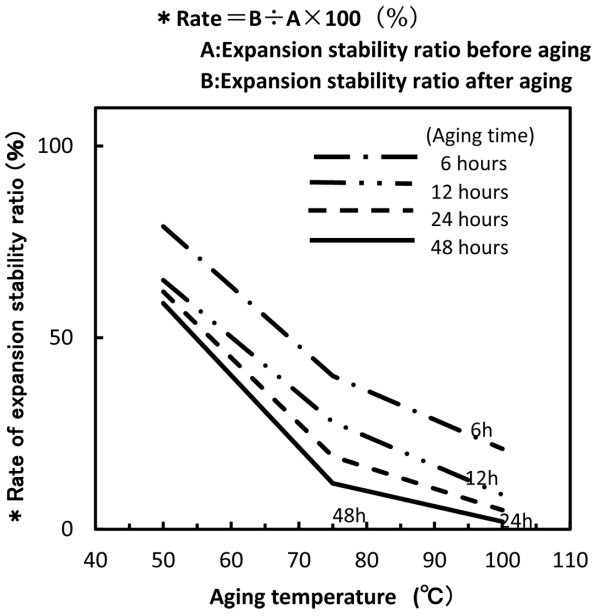

Fig. 1 Relation between aging temperature and expansion ratio

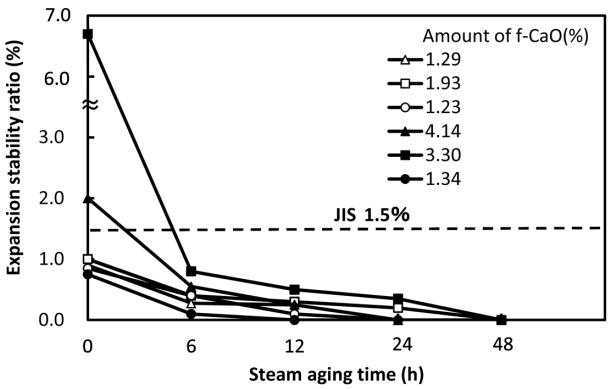

Fig. 2 Relation between aging time and expansion stability ratio

immersion (hereafter called as expansion stability ratio) was investigated. In **Fig. 2**, the relationship between steam aging time and the expansion stability ratio is shown. "0" on the steam aging time axis means the state of the sample before the steam aging treatment. As a result, even in the slag containing high content of free lime with low expansion stability, the expansion stability ratio is sharply improved 6 h after the start of steam aging, and it was confirmed that after 48 h, expansion stability ratios of all kinds of slag were concentrated to the same degree. After various tests with the steam aging test machine, it was judged that the steam aging method is applicable as the steel-slag-expansion-stabilizing method to all kinds of steel slag containing free lime of various contents, and study on development of the steam aging method and application to practicable equipment were commenced.

2.3 Application of steam aging method to practicable equipment

From the result of experiment with the steam aging test machine, as it was found that the slag expansion stability can be obtained in a greatly shortened period of time by steam aging as compared with that with air aging, an practicable equipment capable of handling 300 t at a time was built and its practicability was studied.

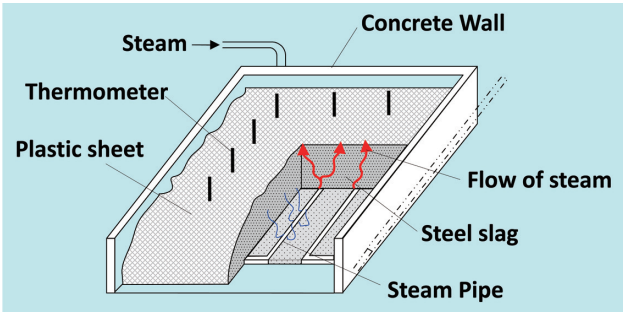

Fig. 3 Outline of steam aging equipment

Photo 1 No. 3 steam aging equipment

In Kokura Works, the first steam aging equipment (No.1) was completed in February 1990 for test and practical use purposes, and the test was continued. As a matter of course, since it was an attempt of unprecedented application of the method to practical use, almost all elements such as arrangement of steam piping, location and number of temperature sensors, and setting of time of raising temperature and of retaining the temperature were studied on trial and error basis. Thus, improvements obtained through operation and know-how were compiled, and No.2 and No.3 equipments were completed in August 1991 and December 1992, respectively.

2.3.1 Outline of steam aging equipment

Figure 3 shows the outline of the steam aging equipment, and **Photo 1** shows the external view of the No.3 steam aging equipment completed in December 1992. The equipment comprises steam ejecting piping installed at the bottom, retaining walls on three sides made of concrete, and a heat-resistant sheet that covers the top to keep steam loss to the minimum possible. Furthermore, to realize the uniform passage of steam, a piping system with numerous loops with devised steam ejecting holes to provide a fully worked-out layer of the diffused steam was provided. And thermocouples were installed at the upper layer of slag so that the aging time of slag could be controlled.

2.3.2 Process of steam aging treatment

As a result of the study on the aging process required for the stabilization of steel slag by the actual steam aging equipment, the then Kokura Works adopted 6 days as one cycle, as shown in **Fig. 4**. This aging treatment process has enabled the shortening of the aging time of longer than 6 months of air aging to one thirtieth of it or less.

2.4 Stability of steam-aging-treated slag

Expansion stability of the steel slag that was steam-aging-processed in the process, as shown in Fig. 4, in the actual steam aging equipment was assessed from various aspects, and as a result of the assessment, it was found that expansion would not be a problem even if it is used as road bed material.

Figure 5 shows the expansion stability ratio of steel slag at 48 h of steam aging treatment in the actual equipment. This result shows

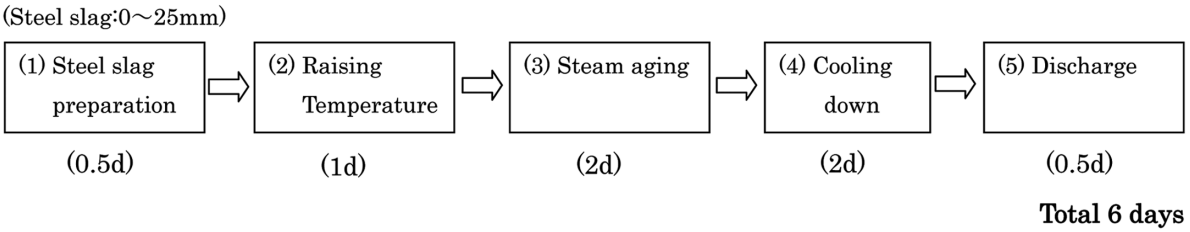

Fig. 4 Steam aging process for steel slag

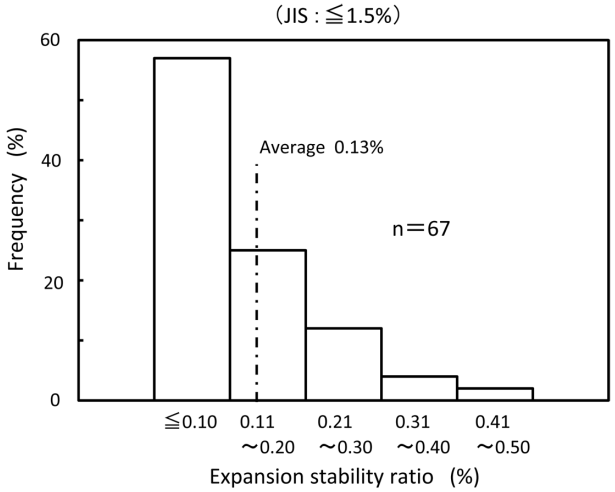

Fig. 5 Expansion stability ratio of steel slag after aging

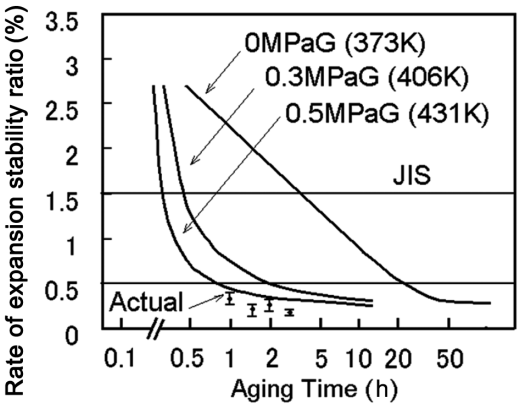

Fig. 6 Relation between aging time and expansion stability ratio

that the expansion stability ratio fully satisfies the standard value of water-immersion expansion stability ratio (expansion stability ratio) of 1.5% or less as specified in JIS A 5015 "Iron and steel slag for road construction,"[3] and it could be confirmed that there is no problem as to the expansion stability. Furthermore, in addition to the expansion stability, its durability was also confirmed and proven in a model road bed test and on actual road test, and the result of the technical study was recognized. Then, in April 1993, the steam-aging-processed steel slag road bed material came to be employed for the first time in a public work. Since then, the steam-aging-processed steel slag has come to be used as road bed material in many public works.

The steam aging method has come to be employed in various works of various companies, and presently constitutes the main stream aging method in the aging of steel slag and has grown to be an indispensable technology.

3. Developments of Pressurized Steam Aging Method and Application to Practical Equipment

Next, development of pressurized steam aging method and application to practicable equipment in Wakayama Works in 1995 are introduced.[4, 5]

3.1 Development of pressurized steam aging

The generally and widely employed steam aging method is conducted under atmospheric pressure; however, from earlier time, Wakayama Works paid attention to the drastic growth of hydration reaction rate of free lime of steel slag realized by pressurized steam and conducted research on the practical use of pressurized steam aging method. In **Fig. 6**, the relation between aging time and the expansion stability ratio under various pressures is shown. In "Iron and steel slag for road construction" of JIS A 5015, the water-immersion- expansion stability ratio (expansion stability ratio) is specified to be 1.5% or less to suppress the expansion of material for road bed use. As Fig. 6 shows, the drastic shortening of aging time is enabled under 0.6 MPa steam pressure when compared with the case of steam under atmospheric pressure. As this shows, use of pressurized steam for aging drastically shortens the aging time and reduction in size and automatic operation of equipment become possible.

However, various subjects exist in employing the pressurized aging method for practical use, and therefore, the development was promoted with the cooperation of Kawasaki Heavy Industries, Ltd. with rich experience in autoclave technology. The points of development of practical equipment are briefly stated hereunder.

3.1.1 Major subjects for practical use

- As slag expands by aging, the equipment needs to be designed to withstand expansion pressure
- Expansion of slag consolidates the slag constrained in a vessel and forms solidified bridges at the time of discharging from the vessel, hindering discharging
- Steel slag is hard and the vessel needs abrasion countermeasures
- To prevent steam leakage, number and space of opening/closing sections should be minimized and sealing parts need countermeasures for the dirt of slag

3.1.2 Major countermeasures for subjects

- To prevent the direct contact of slag with the autoclave, a basket method was employed and aging was applied for each basketful slag. Furthermore, the basket was designed to absorb slag expansion.
- The autoclave is of horizontal type and the basket was carried into and taken out through a single door that is the sole opening/closing section.

With these countermeasures, solution of the above subjects be-

came possible, and in April 1995, full-dressed equipment was completed in Wakayama Works and commercial operation commenced in May of the same year.

3.2 Outline of pressurized steam aging equipment

In **Fig. 7**, the outline of the pressurized steam aging equipment, and in **Photo 2**, the external view of the equipment is shown. The pressurized steam aging equipment comprises a pressure vessel (autoclave), a basket, a carriage car, and a control room. First, steel slag product is loaded to the basket mounted on the carriage car with a shovel car, and the carriage car with the basket travels to the front side of the pressure vessel. The end cover of the pressure vessel is opened, and the basket is carried into the pressure vessel. The end cover is closed and the vessel is charged with steam, and the inside of the pressure vessel is pressurized up to 0.6 MPa and retained for 2–several hours; the aging is then completed.

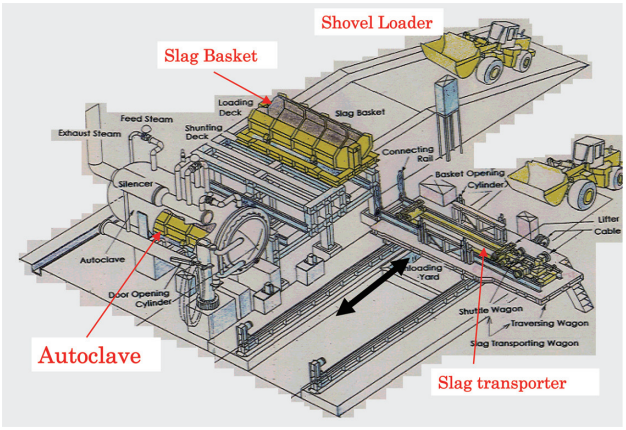

Fig. 7 Outline of pressurized steam aging equipment

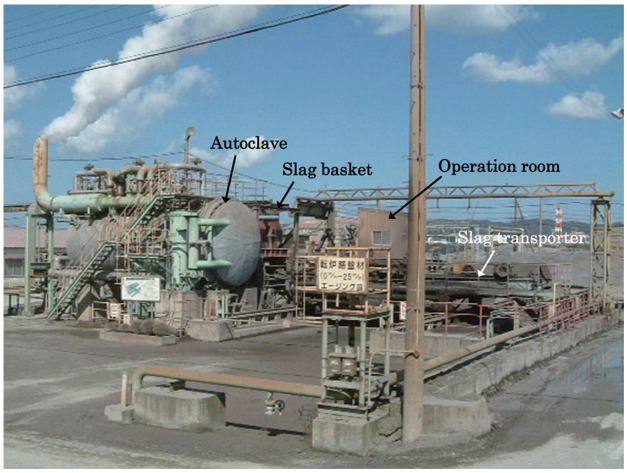

Photo 2 Pressurized steam aging equipment

Introduction of pressurized steam aging could drastically shorten the aging time, and reduction in size and automatic operation of equipment became possible. In addition, the equipment is completely sealed, and steam loss was reduced. Moreover, quality stabilization was achieved with the pressurized steam that uniformly penetrated into the slag layer.

The actual result of this technology was evaluated and awarded with the "Director-General's Award of Industrial Science and Technology Policy and Environment Bureau, Ministry of Economy, Trade and Industry" in 2007 fiscal year Commendation for Resource Recycling Technology system by Clean Japan Center. In addition to Wakayama Works, till date, two other companies in Japan have introduced this technology.

4. Summarization

As technology to solve the big subject of suppressing expansion in using steel slag as road bed material, and methods of steam aging and pressurized steam aging were developed and put into practical operation in the 1990s.

As the expansion characteristics of steel slag differs depending on the contents of free lime and the like, it is considered that operating conditions like setting of aging time and the like are also important technical factors in this technology.

Acknowledgement

Authors wish to express their utmost gratitude to Messrs. GM Masuo Suzaki of Nittetsu Sumikin Ricotec Co., Ltd. and GM Shuhei Saka of Nittetsu Sumikinkoka Co., Ltd. for their great cooperation and direction.

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