

Reduction mechanisms of ash deposition in coal and/or biomass combustion boilers

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HIGHLIGHTS

- ▶ We evaluated adhesion forces between ash and alloy specimens at high temperature.
- ▶ Ni-alloy coated by a thermal spraying technique reduced the adhesion force.
- ▶ Alkali sulfates had a large influence on the adhesion force.
- ▶ Fe₂O₃ (Hematite) was diffused from the metal specimen to among ash particles.

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ABSTRACT

Some ash particles in solid fuels adhere on heat exchanger tube surfaces inside coal and/or biomass combustion boilers. The authors have already proposed a surface treatment on tubes, using a thermal spraying technique, to reduce ash deposition. Understanding reduction mechanisms of the ash deposition is necessary to evaluate effects of the surface treatment technique on the reduction of ash deposition. The reduction mechanisms of the ash deposition were elucidated due to physical and chemical aspects, measuring adhesion forces between the ash particles and some alloy specimens of the tube at high temperature under the simulated boiler conditions. As a result, the adhesion force increased with time and depended on both the ash types and the alloy specimens. The thermal spraying of Ni-alloy, in particular, could reduce the adhesion force. Moreover interface reactions between the ash particles and the alloy specimen played an effective role in increasing the adhesion force, alkali metal compounds in the ash samples also related to an increase of the adhesion force. Fe, which was one of the main alloy elements, diffused into the ash deposition layer beyond the interface. This observation result suggested that the interface reactions of the ash particles with the alloy caused an increase of the adhesion force.

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1. Introduction

Some ash particles produced during solid fuel combustion adhere to surfaces of heat exchanger tubes inside coal and/or biomass combustion boilers. The ash deposition causes heat transfer inhibition such as slagging and fouling, which becomes one of triggers of the boiler operation troubles [1,2]. Basic studies on the deposition behaviors of coal ash on the heat exchanger tubes have been carried out by Raask [1], Benson and Sondreal [3], and Ninomiya [4,5], and also practical studies have been made, such as elucidation of the ash adhesion mechanisms under the boiler combustion conditions [6], measurements on the ash deposition in utility boilers [7], elucidation of the ash adhesion mechanisms in pulverized coal fired (PCF) boiler [8], development of a predictive tool for

the slagging and the deposition control in boilers [9] and discussions of the ash adhesion mechanisms in a pilot plant [10]. Recently, the temperature of the steam has been raised to enhance the net power generation efficiency, and co-combustion with low-rank coal or biomass has also been gradually applied to commercialized PCF boilers. These trends may bring about more severe operation problems [11].

In order to control a long-term ash deposition, it is necessary to discuss a cycle of the growth and drop of the ash deposition layers [7]. This cycle frequency would be influenced by an adhesion force between the ash deposition layer and the tube surface. The residual ash layers would deposit the tube surfaces for a long time, thereby high-temperature corrosion would also occur at the deposition surfaces [12–15]. Both Moza and Austin [16,17] and Abbott et al. [18–20] reported that a relationship between wettability of molten ash on the metal surface and the adhesion force, which affects a deposition rate of the ash particles. Moreover, Kamiya et al. [21]

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have also reported measurements of the adhesion force of the ash particles at high temperatures, in which alkali metal compounds were contained. In those papers mentioned above, however, there has been no one yet who could elucidate the adhesion force between the ash deposition and the tube surface heated for a long period at high temperatures or interface reactions between them under boiler operating conditions.

The present authors have proposed a surface treatment technique for tubes to reduce the ash deposition [22–24]. As previously reported [22], the experiments on ash adhesion were conducted using simulated heat exchanger tubes, on which some kinds of thermal spraying materials were coated. According to the ash deposition experiments under coal combustion in the previous report [22], fine ash particles with alkali metal compounds selectively adhered and formed the initial ash deposition layer. The authors also showed that the interface reactions would be related to the adhesion mechanism [23].

The purpose of this paper is to investigate the adhesion mechanism and the effect of the surface treatment technique on the reduction of the ash force. Moreover the influence of ash types on the adhesion force was elucidated on the basis of direct measurement on the adhesion force and elemental analyses at the adhesion interface using Scanning Electron Microscope–Energy Dispersive Spectroscopy (SEM–EDS) and Micro X-ray Diffraction (Micro-XRD).

2. Experimental

2.1. Measurement of adhesion force

The adhesion force between the ash particles and the metal specimens was measured using the apparatus shown schematically in Fig. 1. The apparatus mainly consisted of a built-in 1 kN load cell, an 8 kW electrical furnace and a circulation unit of cooling water, and a detailed description [23] was given before.

A typical composition of fly ash was shown in Table 1, and in order to carry out accelerating tests alkali sulfates of Na_2SO_4 and K_2SO_4 are added into the fly ash as shown in Table 2 [22,25–28]. Each particle diameter of fly ash, Na_2SO_4 (Melting point: 1157 K) and K_2SO_4 (Melting point: 1342 K) was less than 45 μm . The ash pellet was prepared from fly ash, Na_2SO_4 and K_2SO_4 as follows: (i) 1.0 ml of polyvinyl alcohol was added as a binder into the ash of 6.119 g; (ii) the mixture was placed into a pelletizer of 25 mm diameter and 8 mm high, and then pressed at 20 MPa for 1 h at room temperature, (iii) finally the sample pellet was dried at 313 K for 24 h.

Table 1
Fusion temperatures and compositions of the fly ash employed.

Ash fusion temperature (K)	Oxidizing	Initial deformation	1543
		Hemispherical	1563
		Fluid	1573
Ash composition (wt%)		SiO_2	63.10
		Al_2O_3	20.45
		Fe_2O_3	3.99
		TiO_2	0.94
		CaO	5.84
		MgO	1.37
		Na_2O	1.02
		K_2O	1.76
		p_2o_5	0.21
		SO_3	0.49
	V_2O_5	0.04	
	MnO	0.01	

Table 2
Compositions of the ash sample prepared (wt%).

Fly ash (Table 1)	86.8–100.0
K_2SO_4	0.0–13.2
Na_2SO_4	

Table 3
Elements of alloy specimens employed (wt%).

Specimens	Specimen 1: base metal (JIS-SUS304 and AISI-304)	Specimen 2: thermal spraying (thickness of 200 μm)
Fe	Bal.	3.0
Ni	8.0	Bal.
Cr	18.0	20.0
Others	<2.0	<25.0

The metal specimens shown in Table 3 were first degreased in acetone with an ultrasonic cleaner: they were used as austenite stainless steel for specimen 1, or used as based metal for specimen 2. A thermal spraying material shown in this table was coated 200 μm thick on the based metal with an arc spraying method (specimen 2). After the specimen 1 or 2 was fixed at the lower portion of the tensile testing machine, the ash pellet was set on the specimen. To measure an inner temperature of the sample ash pellet, a thermocouple was installed inside a hole of 8 mm diameter and 4 mm deep in the pellet. An upper rod of austenite stainless steel was put on the ash pellet, and then weight of 30 N was

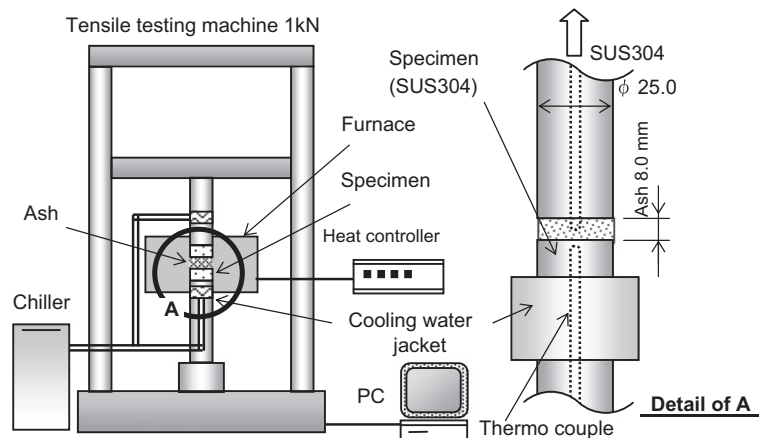


Fig. 1. Schematic of tensile testing machine with an electrical furnace [23].

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