DIRECT MEASUREMENT OF THE ADHESIVE FORCE BETWEEN FLY ASH PARTICLES AT HIGH TEMPERATURES

Tomotsugu Masuda*[1,2], Andy Ingram[1], Zhibing Zhang[1], Jonathan Seville[1]
1- Centre for Formulation Engineering, Department of Chemical Engineering, The University of Birmingham
Edgbaston, Birmingham B15 2TT, U.K.
2- Yokohama Research & Development Centre, Mitsubishi Heavy Industries, Ltd.
1-8-1, Sachiura, Kanazawa-ku, Yokohama, 236-8515, Japan
* Email: gusyou0321@yahoo.co.jp

ABSTRACT

In this work, the adhesive forces between fly ash particles from an incinerator, biomass and coal were measured directly using a novel micromanipulation technique. Particles were heated on a hot stage under a microscope. The sizes of the aggregated particles ranged from 100 to several hundreds of microns. The adhesive force between the fly ash particles at temperatures from ambient to 580^{o}C was measured. The results indicate that the adhesion force of the fly ash particles increased with temperature. The adhesive forces between the particles in the incinerator were significantly larger than those from biomass and coal. Thermal analysis and microscopic observations showed that the increase in adhesion was mainly caused by formation of a liquid bridge between particles at higher temperatures.

1. INTRODUCTION

Ceramic filters, which are known to be highly efficient for gas filtration, are becoming used to reduce dust in thermal power plant operating at high temperatures. Therefore it is expected that ceramic filters may also be applied to incineration plants, for the purpose of reduction of dioxin, high efficiency power generation and effective utilization of fly ash particles. However, it is known that fly ash particles in incinerators are both physically and chemically different from those in power generation plants. The particular focus of the present work is on particle adhesion at high temperatures, which affects the pressure drop and ease of cleaning of such filters. Increased adhesive force between the ash particles at high temperatures can limit long-term process stability and reliability of hot gas filtration. This may determine whether it is feasible to apply ceramic filters to dust reduction in incinerators [1].

The adhesive force between ash particles at high temperatures, which depends on many physical and chemical factors, has been researched [2]. The adhesive force between coal fly ash particles at high temperatures has been investigated and analyzed by many researchers [3-4]. However, it is very difficult to measure the adhesive force between fly ash particles in incinerators at high temperatures because they contain various alkaline ash components that are melting or evaporating, so that the measured adhesive forces vary widely. To our knowledge, there is no published information on the adhesive force between fly ash particles in incinerators. In order to overcome this deficiency, we have developed a novel method based on micromanipulation. This experimental technique has been previously used to measure the adhesive force between ice crystals formed at sub-zero temperatures [5].

In this work, the adhesive force between fly ash particles from an incinerator was measured directly using a novel micromanipulation technique. The measurements were made at temperatures ranging from ambient to 580^{o}C. In order to understand the mechanisms behind the increase in the adhesive force at elevated temperatures, the properties of fly ash particles were measured using a differential scanning calorimeter (DSC) and thermo-gravimetric analysis (TGA), in addition to direct microscopic observation of the changes in the particles due to heat treatment.

2. MATERIALS AND METHODS

The particles used were three samples of fly ashes from incinerator (MSW A, B, C), combustion ashes from biomass (bark) and coal (BFA3) obtained from co-workers at the University of Karlsruhe, Germany, and fly ash collected from a pressurized fluidized bed combustor demonstration plant under the Energy Development Organization of Japan (NEDO) sponsored collaboration. The chemical compositions, which were supplied by Guardian Laboratories Limited in U.K., are shown in table 1. Figure 1 is a schematic diagram of experimental setup for the measurement of adhesive forces between particles at high temperatures. A photograph of the setup is presented in Fig. 2. The hot stage (TMS94/TS1500, Linkam Scientific Instruments, UK) maintains a temperature of up to 1500^{o}C, and is capable of increasing temperature from ambient at a rate of 130^{o}C /min. The particles under investigation were attached to two probes made from a Borosilicate glass capillary tube (OD=1mm and

ID=0.58mm) using a micropuller (PB-7, Narishige, Japan) and microforge (MF900, Narishige, Japan). One probe was designed to be very flexible, and the other was very rigid. They were fixed in holders each connected to a micromanipulator. By means of the manipulators, fine movements of particles on the micrometer scale were achieved. The hot stage was located below a light microscope fitted with a CCD camera, monitor and video tape recorder.

Component (wt %)	Sample					
	MSW A	MSW B	MSW C	Bark	BFA3	NEDO
SiO_2	20.3	11.4	4.9	14.6	15.2	28.8
Al_2O_3	10.4	4.8	2.8	2.8	2.8	14.3
Fe_2O_3	2.5	3.4	0.8	1.9	8.5	1.9
CaO	15.5	18.1	7.7	33.6	37.1	22.8
MgO	2.4	1.6	1.2	3.3	10.1	0.4
Na_2O	7.0	6.1	14.6	1.2	1.3	0.1
K_2O	5.6	6.7	14.4	7.5	0.8	0.3
TiO_2	1.0	0.9	0.5	0.8	0.2	0.5
SO_3	5.0	22.1	37.4	4.7	15.8	6.5
Cl	10.0	7.3	7.6	3.2	0.5	0.3

Table 1 Chemical composition of fly ashes

Table 2 shows the set-up conditions for this measurement. At first, the flexible probe was calibrated using a commercial force transducer (Model 406A, Aurora Scientific Inc., Canada) in order to enable forces to be calculated from the deflections of the probe. For this work, various probes were made with a rage of stiffness such that the force required for deflection was between 0.008 to 9.0 micro-N per micron deflection. Specimens of aggregated particles were attached to each probe by a glue (Super glue, Loctite). The tips of each probe were located on the surface of the hot stage. Then, a pair of particles was brought in to contact using the micromanipulators, with the aid of the monitor, and they were held stationary for 10 minutes. After that, the rigid probe was moved opposite the flexible probe, and the deflection of the flexible probe was measured when they were separated. Next, the hot plate was heated at 50^{o}C /min to a new temperature. The temperature of the hot stage was held constant at this new established temperature for 20min. The pair of particles was made to contact each other again for ten minutes and they were pulled part. The adhesive forces of each sample were measured over a range of temperatures.

In order to determine the mechanism of the increase in the adhesive force, the differential scanning calorimeter (DSC) and the mass loss (TGA) were measured by using a simultaneous thermal analyzer (STA 449 C Jupiter, Netzsch Geraetebau GmbH) under argon at 150 to 1000^{o}C.

In addition, the morphological change in appearance of the particles with increase in temperature was observed on the hot stage using microscopy.

Item	Condition	Remark
Temperature of hot stage	Ambient to 700^{o}C	
Heating rate of hot stage	50^{o}C /min	Fixed condition
Temperature of specimen	Ambient to 580^{o}C	
Contact time of particles	10 min	Fixed condition
Contact length of particles	17 to 243 microns	Due to adhesion
Diameter of aggregated particles	142 to 642 microns	
Atmosphere	Air	

Table 2 Conditions of measurement

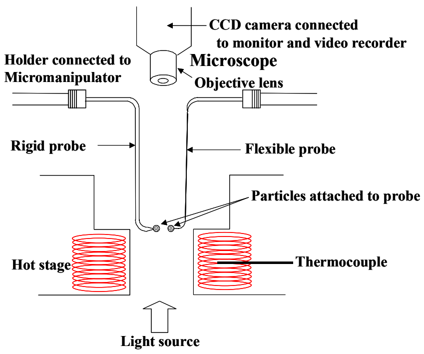


Fig. 1. Schematic diagram of the micromanipulation rig for measuring the adhesive force between particles.

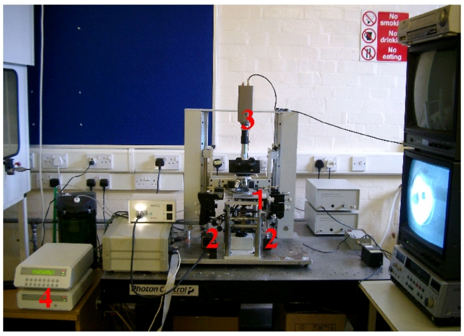


Fig. 2. Photography of the micromanipulation rig for measuring the adhesive force between particles. 1:hot stage; 2: micromanipulator; 3: microscope with CCD; 4: temperature controller.

3. RESULTS AND DISCUSSION

Figure 3 shows the adhesive force per unit contact length versus temperature for all samples tested except MSW C. Overall, the adhesive force increases with the temperature within the temperature range for this work. The adhesive forces of particles in sample MSW C was much larger (maximum 16,000 micro-N/mm), which are beyond what the graph can reasonably show. The amount of low melting point compounds in MSW C deposited on the air heater might be significantly higher than the other samples, so that the particles in MSW C might be very sticky at high temperatures. Furthermore, the adhesive forces for the fly ashes from the incinerator are larger than those from biomass and coal. It is therefore of concern that operation of ceramic filters on incinerators at high temperatures might not be stable.

It is likely that the increase in adhesive force with increasing temperature is associated with chemical binding, hardened binder, and/or bridges forming between the particles. As mentioned earlier, changes in particle morphology on the hot stage were observed directly in addition to thermo-analysis. Micrographs and thermal analysis data for MSW C, for which produced the largest adhesive force at high temperatures among all the samples, are shown in Figs. 4 and 5 respectively. As seen in Fig. 4, the shape of the particles changed as temperature increased, from which it was inferred that there was formation of a liquid. As indicated in Fig. 5, there were some endothermic reactions above 300°C, whilst the mass hardly changed, so that the endothermic reactions implied that a part of particle was melting. Thus, it is suggested that the increased adhesive force with temperature can be considered to be due to formation of a liquid bridge at the contact points between the particles.

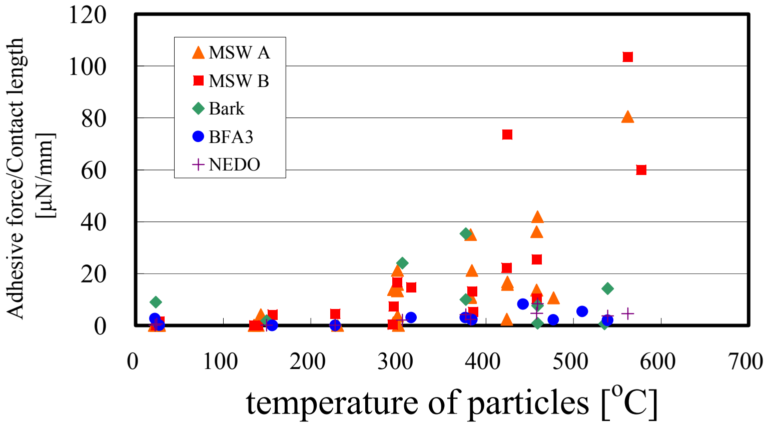
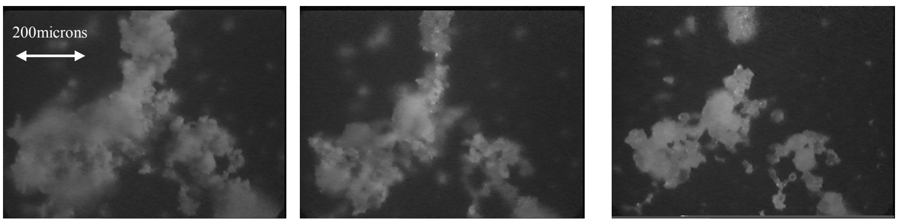


Fig. 3. Effect of temperature on the adhesion force between two particles.



(at Ambient) (at 410°C) (at 630°C)

Fig.4 Microscopic observation of particles changing in morphology with temperature (Sample MSW C)

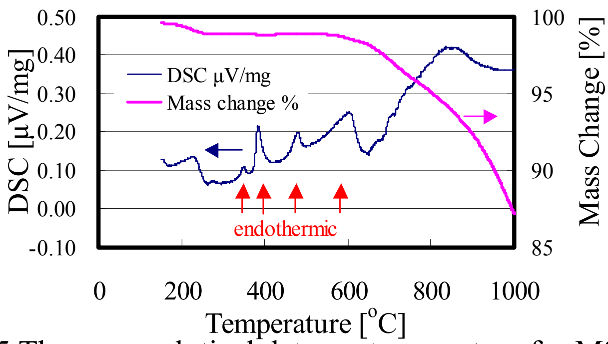


Fig. 5 Thermo-analytical data vs. temperature for MSW C

4. CONCLUSION

In this work, it has been found that the adhesive force of fly ashes from an incinerator increased with temperature up to 580°C. The adhesive forces between the particles in the incinerator were significantly larger than those from biomass and coal. The results here give cause of concern for the operation of ceramic filters in conjunction with incinerators. Thermo-analysis and microscopic evidence suggests that the mechanism of the increasing adhesive force with temperature may be due to formation of liquid bridge at contact points between particles.

5. ACKNOWLEDGEMENTS

This work was supported by grants from Mitsubishi Heavy Industries, Ltd (MHI). The authors also thank Prof. Gerhard Kasper of the University of Karlsruhe, MHI and NEDO for providing samples for test. Financial assistance from NEDO under the cooperative grant scheme is gratefully acknowledged.

REFERENCES

[1] Seville J.P.K. and R. Clift: Gas cleaning in demanding applications, Blackie/Kluwer, London (1997)
[2] Berbner, S., F. Loffler, Powder Technology, **78**, 273-280 (1994)
[3] Kanaoka, C., Hata, M., Makino, H. Powder Technology, **118**, 107-112 (2001)
[4] Kamiya, H., Kimura, A., Yokoyama, T., Naito, M., Jimbo, G., Powder Technology, **127**, 239-245 (2002)
[5] Fan, X., Ten, P., Clarke, C., Bramley, A., Zhang, Z., Powder Technology, **131**, 105-110 (2003)