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Study on the effects of coal-ash-slag deposition on boiler tubes in a coal-fired thermal power plant

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Coal combustion in a thermal power plant generates plenty of ashes, which gets melted at high temperature. These melted ashes, i.e. slag, gets deposited on the external surface of the boiler tube in the furnace and stick to it. This slag greatly affect the heat transfer, which leads to reduction in the efficiency of the boiler. Also, slag deposition slowly corrodes the external surface of the tube. In this paper, a typical slag deposited tube was collected from a coal fired thermal power plant and metallographic analysis was carried out on this tube and the results were compared with an unexposed tube of same material, diameter and thickness. It is concluded from the analysis that there are no significant changes in microstructure, hardness values as well as inslag compositions.

Keywords: *Boiler tube, slag, micro-structure, coal fired, slag indices*

1.0 INTRODUCTION

Coal is used as aprimary fossil fuel for combustion in thermal power plant. Indian coals have a very high percentage of ash (35 – 40 weight % on average) i.e. probability for formation of ash is more in the boiler. During the process of combustion, at very high temperature the ashes gets melted. When these melted ashes falls on the boiler tube surface in the furnace, it becomes chilled and solidifies. These melted ashes which gets deposited on the tube surface are called slag [1,2]. Once an initial deposit layer has formed, its surface tends to become sticky and most of the incident particles will be held on the surface, causing a buildup of layer on the surface [3]. Ash deposition on the furnace water walls and in the super-heater of a boiler greatly affect the efficiency of heat exchange in the boiler [4]. Accumulation of fly ash slag on the surface of the boiler tube reduces the available heat surface area which leads to heat loss. It acts like an insulator on the surface of the tube, which restricts the radiation heat transfer from the metal surface to the working fluid; also change in flue gas flow pattern inside the furnace which intent the reduction of the efficiency of boiler. The slag accumulation slowly corrodes the external surface of the tube which may lead to failure. Therefore, the utilities experiences an unscheduled boiler shutdown [5].

Keeping in view, the effect of slag on boiler tube,an extensive literature survey has been carried out. The outcome of literature survey reveals that most of the work has been carried out mainly on the combustion process of coal and formation of the fly ash, slag including characterization to control the sticking viscosity of the slag [6-10]. Less work have been reported on the effect of slags on boiler tube. Hence, these issues need to be addressed through comprehensive research work. In this present work, effects of slag on the micro-structure of a slag deposited boiler tube compared to an unexposed tube has been studied.

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2.0 EXPERIMENTAL PLANS

- Collection of slag deposited boiler tube from a coal fired thermal power plant.
- Physical evaluation and slag characterization.
- Testing of boiler tube to study the effect of corrosion, micro-structure and hardness.

3.0 LABORATORY WORKS

Slag deposited tube drawn from the coal fired thermal power plant (140 MW) were taken for metallographic analysis. The plant has crossed 1,00,000 running hours of operation. The slag tube was collected from the platen super heater zone. An unexposed tube of the same material, diameter & thickness and also some slag powder were collected to study the characterization.

3.1 Characterization methods

Two samples (Sample 1- Slag deposited tube and Sample 2- Unexposed tube) were cut cross-sectionally for the metallographic analysis. An image of the as received tube is shown in Figure 1 and Figure 2 respectively.

Visual inspection: The slag deposited tube was examined through naked eye and later through a magnifying glass. It has been observed that the fire-side surface of the tube was covered with a brown color adherent slag deposition with slightly corroded. The dimensions of the tubes were measured. No wall thinning was observed.

FIG. 1 SLAG DEPOSITED TUBE

FIG. 2 UNEXPOSED TUBE

Chemical composition analysis: The materials of the tubes were analyzed through spectro (spark method). The chemical compositions are shown in Table 1.

TABLE 1

CHEMICAL COMPOSITIONSOF TUBE MATERIAL

	Elemental concentration (Wt %)				
	Fe	**C**	**Si**	**Cr**	**Mn**
Slag deposited Tube	95.11	1.98	1.07	1.38	0.45
Unexposed Tube	97.82	-	0.93	1.25	-

Hardness test: The Vickers hardness tests were carried out by the Micro hardness tester (Model No. ZWICK 3212) in different locations on the cross-sections of the samples on both the tubes. The brief results are given in Table 2.

TABLE 2

VICKERS HARDNESS VALUE FOR TUBES

	Slag Deposited Tube	**Unexposed Tube**
Hardness (HV)	148-156	128-136

Metallographical analysis: For Metallo- graphical analysis, pieces from cross-section of sample were taken from both the tubes(slag deposited and unexposed tubes). The samples were polished with emery paper and etched. The microstructure and morphology of the tubes were examined under the optical microscope (Model No. ZEISS Axio CAM MRc5).

Figure 3 & 4 represents the microstructure for slag deposited tube with fire side and steam side respectively. Figure 5 & 6 shows the microstructure for unexposed tube with fire side and steam side respectively.

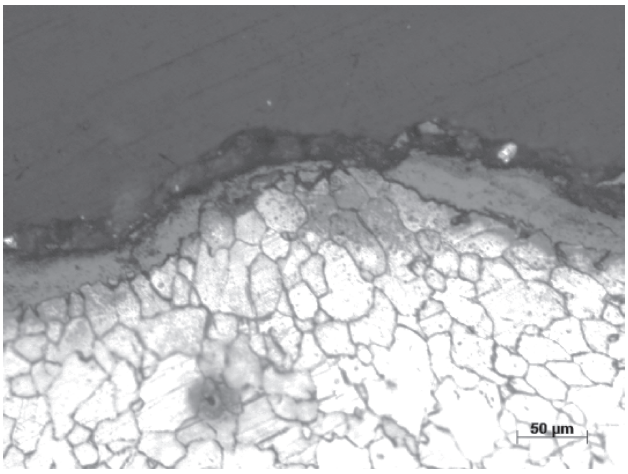

FIG. 3 MICRO-STRUCTURE FOR SLAG DEPOSITED TUBE (FIRE SIDE)

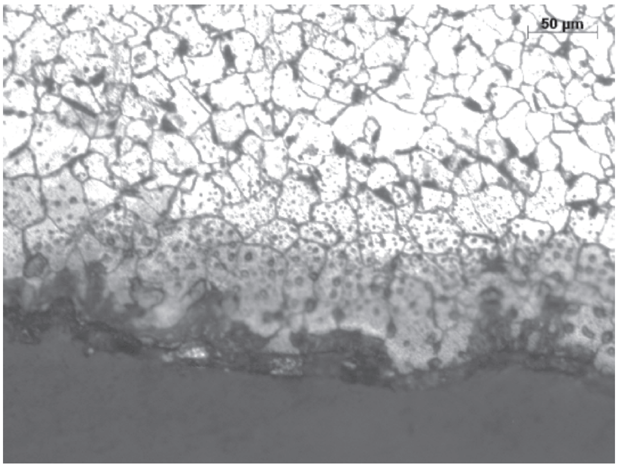

FIG. 4 MICRO-STRUCTURE FOR SLAG DEPOSITED TUBE (STEAM SIDE)

The slag deposited tube shows non-uniform deposition of slag on the outer surface of the tube. The micro-graph of both tube shows pearlite in ferrite matrix and grain boundary remained intact.

SEM and EDAX analysis: For chemistry and growth of slag scales EDAX and SEM analysis were used.

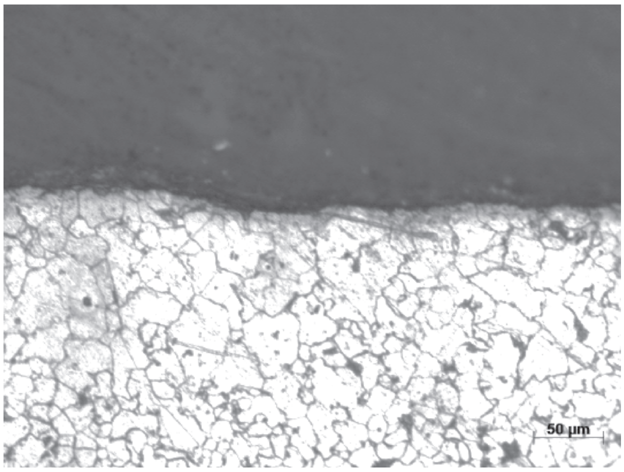

FIG. 5 MICRO-STRUCTURE FOR UNEXPOSED TUBE (FIRE SIDE)

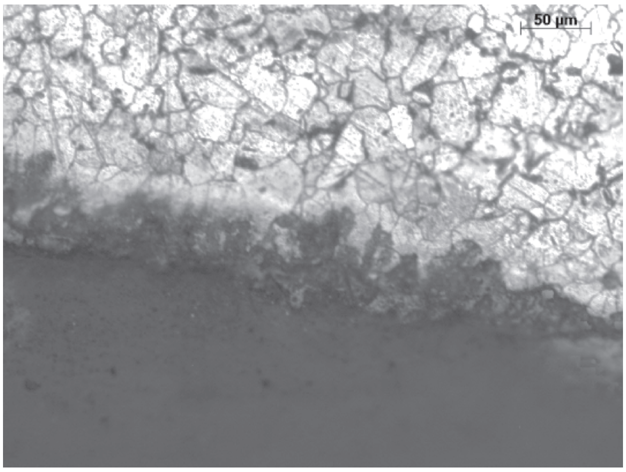

FIG. 6 MICRO-STRUCTURE FOR UNEXPOSED TUBE(STEAM SIDE)

The average result of the elemental analysis of slag powder is shown in Table 3.

TABLE 3

ELEMENTAL ANALYSIS OF SLAG POWDER

Al_2O_3	30.19 %
SiO_2	51.38 %
K_2O	1.73 %
CaO	1.12 %
TiO_2	1.66 %
Fe_2O_3	12.87 %
Na_2O	1.05 %

Scale morphology and EDX spectrum of slag powders are shown in Figure 7 & 8 respectively.

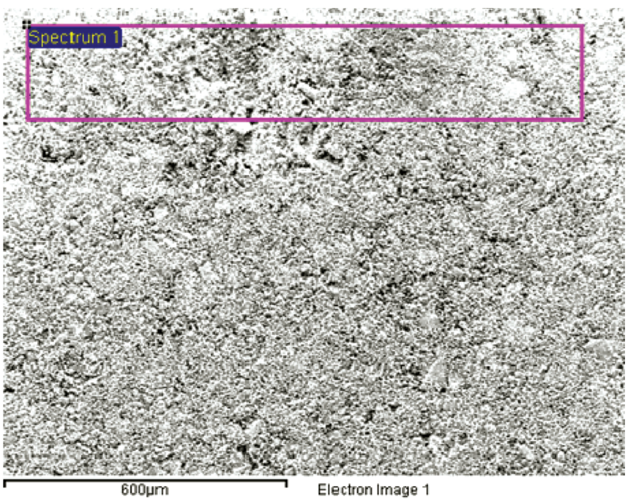

FIG. 7 SCALE MORPHOLOGY OF SLAG POWDER

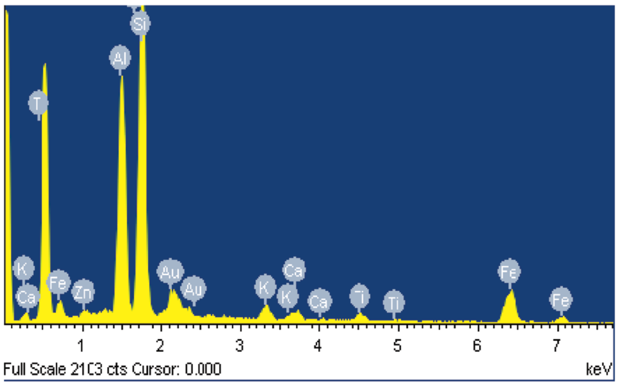

FIG. 8 EDX SPECTRUM OF SLAG POWDER

3.2 Characteristic indices of the slagging process

From Table 1 we can calculate the coal slagging indices as follows,

Base/Acid Ratio: 0.2015

$$\frac{(Fe_2O_3+CaO+K_2O+Na_2O)}{(SiO_2+Al_2O_3+TiO_2)} \quad \text{....(1)}$$

Iron plus Calcium:13.99%

$$Fe_2O_3+CaO \quad \text{....(2)}$$

Silica Ratio (SR): 78.6

$$SR = \frac{SiO_2 \text{ x } 100\%}{SiO_2 + Fe_2O_3 + CaO} \quad \text{....(3)}$$

Glassy / sticky behaviour of ashes are found due to the high percentage of SiO_2 (>50%) and low percentage of Fe_2O_3 and CaO in their slag constituents. A high value of SR (SR>72) denotes highly viscous slag and consequently a low tendency to cause slagging [11]. High iron content in the slag is an important parameter to determine the ash slagging potential. $Fe_2O_3 < 6\%$ has a low slagging tendency. Higher value of (B/A) ratio causes lower of coal fusion temperature [12] and increases the slagging potential.

4.0 RESULTS AND DISCUSSIONS

It is observed that hardness values for both the tubes are in the range. Slight higher value of hardness in slag deposited tube may be due to heat exposition in the furnace. Micro-structure analysis of the tubes (Figure 3 to 6) shows no significant changes. No micro crack was observed on the surface of the slag deposited tube. The Fireside slag thickness were observed not uniform and its thickness is about 30-40 micron. The slag composition shows that there was a high percentage of silica and aluminium oxide (more than 80%) compared to ferric oxide and calcium oxide.

5.0 CONCLUSION

In this paper effects of slag deposition on micro-structure of the boiler tube surface has been discussed. The following conclusions are made,

- There is no significant change in micro-structure of slagged tube compared to an unexposed tube.
- A slight increase in Hardness value was observed (about 15%).
- No significant variation in slag powder compositions.

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REFERENCES

[1] H Bilirgen, Slagging in PC boilers and developing mitigation strategies, Fuel, Vol. 115, pp. 618–624, Jan. 2014.

[2] W Song, L Tang, X Zhu, Y Wu, Y Rong, Z Zhu, and S Koyama, Fusibility and flow properties of coal ash and slag,Fuel, Vol. 88, No. 2, pp. 297–304, 2009.

[3] P Furmański, Thermal And Radiative Properties Of Ash Deposits On Heat Transfer Surfaces Of Boilers,No. 79, 1995.

[4] M U Degereji, D B Ingham, L Ma, M Pourkashanian, and A Williams, Prediction of ash slagging propensity in a pulverized coal combustion furnace,Fuel, Vol. 101, pp. 171–178, Nov. 2012.

[5] Q Fang, H Wang, Y Wei, L Lei, X Duan, and H Zhou, Numerical simulations of the slagging characteristics in a down-fired, pulverized-coal boiler furnace,Fuel Process. Technol., Vol. 91, No. 1, pp. 88–96, Jan. 2010.

[6] M U Degereji, S R Gubba, D B Ingham, L Ma, M Pourkashanian, A Williams, and J Williamson, Predicting the slagging potential of co-fired coal with sewage sludge and wood biomass,Fuel, Vol. 108, pp. 550–556, Jun. 2013.

[7] W Song, L Tang, X Zhu, Y Wu, Z Zhu, and S Koyama, Flow properties and rheology of slag from coal gasification,Fuel, Vol. 89, No. 7, pp. 1709–1715, 2010.

[8] M U Garba, D B Ingham, L Ma, M U Degereji, M Pourkashanian, and A Williams, Modelling of deposit formation and sintering for the co-combustion of coal with biomass,Fuel, Vol. 113, pp. 863–872, Nov. 2013.

[9] A Blokh, Y Zhuravlev, and S Tinkova, An analysis of radiant heat transfer in furnace chambers burning slagging coals, Journal of heat mass Transfer, Vol. 35, No. I, 1992.

[10] M Mitchner, Flyash radiative properties and effects on radiative heat transfer in coal-fired systems, Vol. 32, No. 4, 1989.

[11] M U Degereji, D B Ingham, L Ma, M Pourkashanian, and A Williams, Numerical assessment of coals/blends slagging potential in pulverized coal boilers,Fuel, Vol. 102, pp. 345–353, Dec. 2012.

[12] M Pronobis, S Kalisz, and M Polok, The impact of coal characteristics on the fouling of stoker-fired boiler convection surfaces,Fuel, Vol. 112, pp. 473–482, Oct. 2013.