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Technical Progress Report No.12

Analysis/Control of In-Bed Tube Erosion
Phenomena in the Fluidized Bed
Combustion (FBC) System

to

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SUMMARY

This technical report summarizes the research work performed and progress achieved during the period of July 1, 1995 to October 30, 1995.

The characteristics of resistant coatings were determined and related to metal wastage of in-bed tubes in FBC under various laboratory test conditions. The tests were conducted at high impact velocity, 30 m/s, and short exposure time (4 hours) to minimize oxidation of surrounding surface specimens. No oxidation layer founded on the worn surfaces of AISI 1018 carbon steel.

The eroded surfaces and cross sections of coatings tested at high velocity were investigated. The surfaces of coating specimens were eroded through a combined mechanism of brittle and ductile modes. These mechanical properties of materials are strongly dependent on the composition and microstate of materials, rather than to their hardness.

For high velocity testing, all of the coatings exhibited "brittle behavior", i.e. the erosion rate at shallow angles was higher than at steep angles and maximum erosion rate at impact angle of 90° .

Tests will be continued and compared with erosion test results for different thermal sprayed coatings.

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SECTION 1

Erosion Resistant Coatings of In-Bed Tube Materials

In order to understand the characteristics of erosion resistant coatings of in-bed tubes in FBC, different thermal-sprayed coatings [1] were tested under different test conditions.

1.1 Test Conditions

a. Test Specimens and Materials

AISI 1018 low carbon steel and two thermal spray coatings were used as target materials. High Velocity Oxygen (HVOF) thermal spraying (DS-200) was employed as the coating process for one specimen. For the other specimen, wire arc spraying (Armacor M) was employed. The characteristics of the test specimens and the preparation of specimens was explained in the previous report [1].

b. Test Procedures

The tests were carried out in the elevated temperature blast nozzle-type tester to simulate material wastage of in-bed tubes in FBC. Quartz silica particles having a mean size of 742 μm were used as the erodent particles. The tests were carried out at a temperature of 300 $^{\circ}\text{C}$ and impact angles of 30 $^{\circ}$, 45 $^{\circ}$, and 90 $^{\circ}$. A test time of 4 hours was used at a particle loading of 375 g. The higher particle impact velocity (30 m/s) was employed to provide comparison with the test results [1] of low particle impact velocity.

The material wastage of the specimen was determined by weight measurements and by measuring the thickness change of the specimens through the area of greatest material loss. Since the weight measurement included the material loss, the remaining oxide scale, and erodent deposition on the surface, the thickness change was considered the more valid measurement of material wastage. The morphologies of the specimens were examined and analyzed using scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS).

SECTION 2

Results and Discussion

At high impact velocity, 30 m/s, the short exposure time of 4 hours minimized oxidation of surrounding surfaces of specimens, thus minimizing potential weight gain. No oxidation layer formed on the worn surface of the specimen of AISI 1018 steel [2]. The eroded surface of AISI 1018 specimens tested under high velocity exhibited typical ductile erosion behavior as indicated by craters, striations, platelet formation, and plastic flow [3].

For the material wastage of the coating specimens, the data clearly shows that in the high velocity impact tests, erosion rates were higher and erosion behavior was markedly different from that seen in the low velocity testing. At steep impact angles, all of the coatings demonstrated lower resistance than the AISI 1018 steel. These results are shown in Table 1. Compared to testing at low velocity [1], there was an opposite angular dependence of erosion rate for coatings tested at high velocity. For high velocity testing, all of the coatings exhibited "brittle behavior", i.e. the erosion rate at shallow angles was higher than at steep angles and the maximum erosion rate occurred at impact angle of 90° .

Table 1 The Material Thickness Loss at High Velocity (30 m/s)

Target Material,	Impact Angles:	Thickness Loss (μm)			Thickness Loss Rate (nm/g)		
		30°	45°	90°	30°	45°	90°
AISI 1018 steel		64	86	49	171	229	131
DS-200		80	150	336	213	400	896
Armacor M		123	194	354	328	517	944

It is worth noting that when eroded at high velocity and shallow impact angles, the hardness of the coatings had an inverse relationship to the erosion rate. In this case, references [4,5] confirm based on the indentation fracture mechanics of the target materials, that the erosion rate should be inversely proportional to the hardness of the surface of the target materials.

The materials conventionally thought of as brittle, such as ceramic and cermet coatings, are usually eroded by the brittle cracking mechanism and suffer maximum erosion rate at normal impingement. However, the angular dependence of erosion rate is not a characteristic of material alone, but depends also on the conditions of erosion. Nominally brittle materials eroded by very small particles, or eroded at low impact velocity. The brittle materials do show ductile behavior under these conditions.

Figures 1, 2, and 3 show the morphologies of the coating specimens, which were examined using scanning electron microscopy (SEM). As shown in Figures 1 and 2, the microscopic examination of specimens showed signs of ductile deformation as indicated by small craters, striations, gouges, and indentations in their surfaces, especially when eroding at shallow angle. Figure 3 shows more brittle than ductile mode in the surface of the coating specimen. In this study, however, the erosion rate also correlated with the ductility and fracture toughness of target materials. These mechanical properties of materials are strongly dependent on the composition and microstructure of materials.

a) HVOF $\text{Cr}_3\text{C}_2\text{-NiCr}$ coating ($V=30 \text{ m/s}$, $\alpha=30^\circ$).

b) HVOF $\text{Cr}_3\text{C}_2\text{-NiCr}$ coating ($V=30 \text{ m/s}$, $\alpha=90^\circ$).

Figure 1 The surface of HVOF thermal spray coating (DS-200) eroded at high velocity, 30 m/s.

c) HVOF Cr_3C_2 coating ($V=30 \text{ m/s}$, $\alpha=30^\circ$).

d) HVOF Cr_3C_2 coating ($V=30 \text{ m/s}$, $\alpha=90^\circ$).

Figure 2 The surface of HVOF Cr_3C_2 coating eroded at high velocity, 30 m/s.

e) Arc-sprayed FeCrSiB coating ($V=30 \text{ m/s}$, $\alpha=30^\circ$).

Figure 3 The surface of wire arc spray coating (Armacor M) eroded at high velocity, 30 m/s.

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