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BETHLEHEM, PA

Cermet Composite Thermal Spray Coatings for Erosion and Corrosion Protection in Combustion Environments of Advanced Coal-Fired Boilers

Semiannual Technical Report Prepared for U.S. Department of Energy

Project Period: 8/14/96 - 1/14/97

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B.F. Levin, J.N. DuPont, and A.R. Marder

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Disclamer

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EXECUTIVE SUMMARY

Research is presently being conducted to determine the optimum ceramic/metal combination in thermally sprayed metal matrix composite coatings for erosion and corrosion resistance in new coal-fired boilers. The research will be accomplished by producing model cermet composites using *powder metallurgy and electrodeposition methods* in which the effect of ceramic/metal combination for the erosion and corrosion resistance will be determined. These results will provide the basis for determining the optimum hard phase constituent size and volume percent in thermal spray coatings. Thermal spray coatings will be applied by our industrial sponsor and tested in our erosion and corrosion laboratories.

In the first six months of this project, *bulk powder processed* Ni-Al_2O_3 composites were produced at Idaho National Engineering Laboratory. The results of microstructural characterization of these alloys were presented in the first semiannual report [1]. The composite samples contained 0, 21, 27, 37, and 45 volume percent Al_2O_3 with an average particle size of 12 um. An increase in the volume fraction of alumina in the nickel matrix from 0 to 45% led to a significant increase in hardness of these composites.

During the second six months model Ni-Al_2O_3 cermet *coatings* with various volume fractions of alumina were produced. To deposit Ni-Al_2O_3 coatings, an electrodeposition technique was developed and coatings with various volume fractions (0-35%) of Al_2O_3 were produced. The experimental procedure and microstructural characterization of Ni-Al_2O_3 electrodeposited cermet coatings were presented in the last progress report [2]. The powder and electrodeposition processing of Ni-Al_2O_3 composites provide the ability to produce a different volume fractions of the second phase without changing the composition of the matrix material. Therefore, the effect of hard second phase particle volume fraction and size on erosion resistance can be analyzed.

During the last six months, powder processed and electrodeposited composites were tested in the erosion simulator (Al_2O_3 erodent, 40 m/s velocity, and 90^0 impact angle) and their relative erosion resistances were determined. It was found that electrodeposited Ni-Al_2O_3 composites containing small Al_2O_3 particles ($\approx$ 1um) showed better erosion resistance than powder processed Ni-Al_2O_3 composites containing large Al_2O_3 particles ($\approx$12 um). Also, an increase in the volume fraction of Al_2O_3 particles in powder processed alloys led to a decrease in erosion resistance. For both powder processed and electrodeposited Ni-Al_2O_3 composites, addition of hard Al_2O_3 particles did not improve erosion resistance compared with pure nickel. The experimental procedure, results, and discussion of the erosion tests are presented in this progress report.

I. INTRODUCTION

Present coal-fired boiler environments remain hostile to the materials of choice since corrosion and erosion can be a serious problem in certain regions of the boiler. Recently, the Clean Air Act Amendment is requiring electric power plants to reduce NO_x emissions to the environment. To reduce NO_x emissions, new low NO_x combustors are utilized which burn fuel with a substoichiometric amount of oxygen (i.e., low oxygen partial pressure). In these low NO_x environments, H_2S gas is a major source of sulfur. Due to the sulfidation process, corrosion rates in reducing parts of boilers have increased significantly and existing boiler tube materials do not always provide adequate corrosion resistance. Combined attack due to corrosion and erosion is a concern because of the significantly increased operating costs which result in material failures.

One method to combat corrosion and erosion in coal-fired boilers is to apply coatings to the components subjected to aggressive environments. Thermal spray coatings, a cermet composite comprised of hard ceramic phases of oxide and/or carbide in a metal binder, have been used with some success as a solution to the corrosion and erosion problems in boilers. However, little is known on the effect of the volume fraction, size, and shape of the hard ceramic phase on the erosion and corrosion resistance of the thermally sprayed coatings. It is the objective of this research to investigate metal matrix composite (cermet) coatings in order to determine the optimum ceramic/metal combination that will give the best erosion and corrosion resistance in new advanced coal-fired boilers.

II. EXPERIMENTAL PROCEDURE

During the last six months electrodeposited and powder processed Ni-Al_2O_3 composites with different volume fractions of Al_2O_3 particles (0-45%) were tested in the erosion simulator. Because powder and electrodeposited alloys have different Al_2O_3 particle sizes with similar volume fractions, the effect of particle size and volume on erosion resistance of Ni-Al_2O_3 composites can be analyzed. Microstructural characterization of Ni-Al_2O_3 composites was presented in the previous progress reports [1,2].

A schematic diagram of the erosion tester used in this study is shown in Figure 1. The system is driven by an air compressor and the air is cleaned through a series of filters to remove any entrained water. The flow meter and pressure regulator control the amount of air that flow through the system and the air can be heated by two inline fluid heaters. The erosive particles are fed into the air stream with a screw feeder to ensure constant feed rates. The particles and air are accelerated and impinge upon the sample at any angle between 0° and 90°. The particle velocity distribution prior to impact is directly measured with a Laser Doppler Velocometer (LDV).

The standard test conditions that were chosen for this study are listed in Table I. Five to seven different erosion exposure times (30min. intervals) were used in this study to adequately obtain the weight loss vs. time plot for each material, the slopes of which yield the steady state erosion rate. To quantify weight loss during the erosion experiments, the erosion specimens were ultrasonically cleaned in acetone and weighed before and after the erosion tests to the nearest 0.1 mg.

III. RESULTS AND DISCUSSION

Erosion weight loss versus time plots for powder processed and electrodeposited composites are shown in Figure 2a and b. The steady state erosion rates for all alloys are presented in Table II. For the *powder processed* Ni-Al_2O_3 alloys, the composite with the largest volume fraction of Al_2O_3 (45 vol. %) showed the highest erosion rate, while pure Ni showed the lowest erosion rate. Similar results were observed for the *electrodeposited* Ni-Al_2O_3 composites for which alloy with the largest Al_2O_3 content (39 vol.%) had the highest erosion rate and pure Ni exhibited the lowest erosion rate.

The effect of volume fraction of Al_2O_3 particles on erosion resistance of the Ni-Al_2O_3 composites is shown in Figure 3. It can be seen that an increase in Al_2O_3 content led to an increase in erosion rate of the composites. Also, electrodeposited Ni-Al_2O_3 alloys exhibited better erosion resistance than powder processed Ni-Al_2O_3 alloys. Although both types of Ni-Al_2O_3 composites contained approximately the same volume fraction of Al_2O_3 particles, the size of these particles is an order of magnitude smaller for the electrodeposits than for the powder alloys ($\approx$1um and 12 um respectively). Therefore, for the current erosion test conditions, small Al_2O_3 particles in a Ni matrix were more beneficial in terms of erosion resistance than large Al_2O_3 particles. Similar results were obtained by Lindsley [3] for the Fe-Fe_3C alloy system in which composites with small carbide (Fe_3C) particles were more erosion resistant than those with large particles. Typically, small particles are less likely to fracture during impact than large particles because the former contain fewer preexisting defects (i.e., cracks). Preexisting defects in brittle ceramic particles create stress concentrations and may cause rapid crack propagation and fracture during the impact. It is possible that the main cause of the weight loss in tested Ni-

Al_2O_3 is cracking and removal of brittle Al_2O_3 particles. Therefore, small particles can provide better erosion resistance than larger particles. However, neither size particles provided any benefit to erosion resistance of Ni-Al_2O_3 alloys compared with pure Ni. Also, cracking and removal of the Al_2O_3 particles may be responsible for an increase in erosion rate with an increase in volume fraction of Al_2O_3 as shown in Figure 3. The microstructural analysis of the tested alloys will be conducted to determine the extent of the Al_2O_3 particles fracture and subsequent erosion mechanism in Ni-Al_2O_3 composites.

IV. CONCLUSIONS

Based on the results of the erosion tests for the Ni-Al_2O_3 powder processed and electrodeposited composite alloys the following can be concluded:

1. An increase in volume fraction of Al_2O_3 particles from 0 to 45 vol. % led to an increase in erosion rate of the composites. Pure Ni alloys showed the best erosion resistance.
2. For the current erosion test conditions, small Al_2O_3 particles in a Ni matrix (electrodeposited alloys, Al_2O_3 size $\approx$ 1um) were more beneficial in terms of erosion resistance than large Al_2O_3 particles (powder alloys, Al_2O_3 size $\approx$ 12um).

V. PLANS FOR COMING YEAR:

In the next six months, the microstructure of powder and electrodeposited cermet alloys after erosion will be analyzed using light optical and scanning electron microscopy techniques. Also, microhardness tests will be performed on all alloys to determine the extent of plastic deformation beneath the eroded surface. From these results we expect to determine the mechanism of erosion for the Ni-Al_2O_3 metal-matrix composites.

VI. REFERENCES

1. B.F. Levin, J.N. DuPont, and A.R. Marder, Semiannual Progress Report Prepared for U.S. Department of Energy The Period July 1995 through January 1996, Lehigh University, Energy Reseacrh Center, Bethlehem, PA 18015.

2. B.F. Levin, J.N. DuPont, and A.R. Marder, Semiannual Progress Report Prepared for U.S. Department of Energy The Period February 1996 through July 1996, 96-500-09-31, Lehigh University, Energy Reseacrh Center, Bethlehem, PA 18015.

3. B.L. Lindsley, Ph.D Thesis, Department of Materials Science, Lehigh University, 1996.

Table I. Erosion tests conditions.

Eroded Sample Planar Dimensions	9 mm x 9 mm
Sample Temperature	20°C
Erodent Particle Velocity	40 m/s ±5 m/s
Erodent Particles Flux	7.2 mg/(mm^2/sec)
Impingement Angle	90°
Erodent	angular alumina (Al_2O_3)
Erodent Size Range	355-425 μm
Average Diameter Of The Erodent	380 μm

Table II. Erosion rates for the Ni-Al_2O_3 alloys tested.

Alloy	**Erosion Rate (mg/min) x 10^2**
Ni powder processed	8.5 ± 0.1
Ni-21vol.%Al_2O_3, powder processed	11.2 ± 0.1
Ni-27vol.%Al_2O_3, powder processed	11.9 ± 0.1
Ni-37vol.%Al_2O_3, powder processed	16.3 ± 0.6
Ni-45vol.%Al_2O_3, powder processed	17.1± 0.3
Ni electrodeposited	7.5 ± 0.1
Ni-5vol.%Al_2O_3, electrodeposited	9.0 ± 0.1
Ni-23vol.%Al_2O_3, electrodeposited	9.1± 0.2
Ni-32vol.%Al_2O_3, electrodeposited	8.6 ± 0.1
Ni-39vol.%Al_2O_3, electrodeposited	10.5 ± 0.1

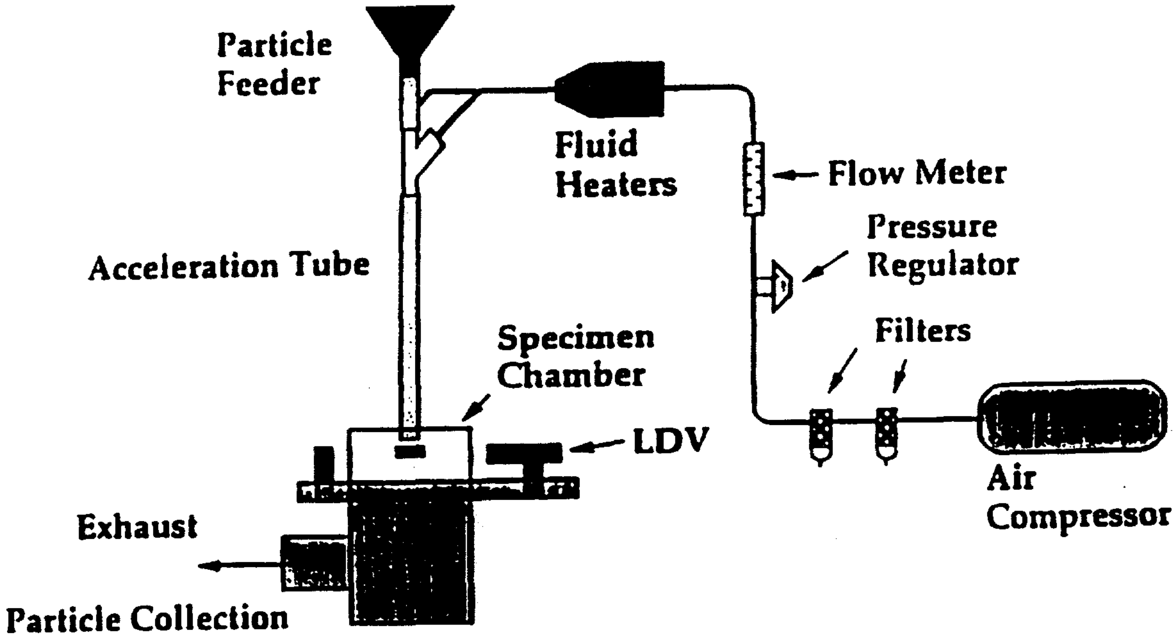

Figure 1. Schematic diagram of the erosion apparatus.

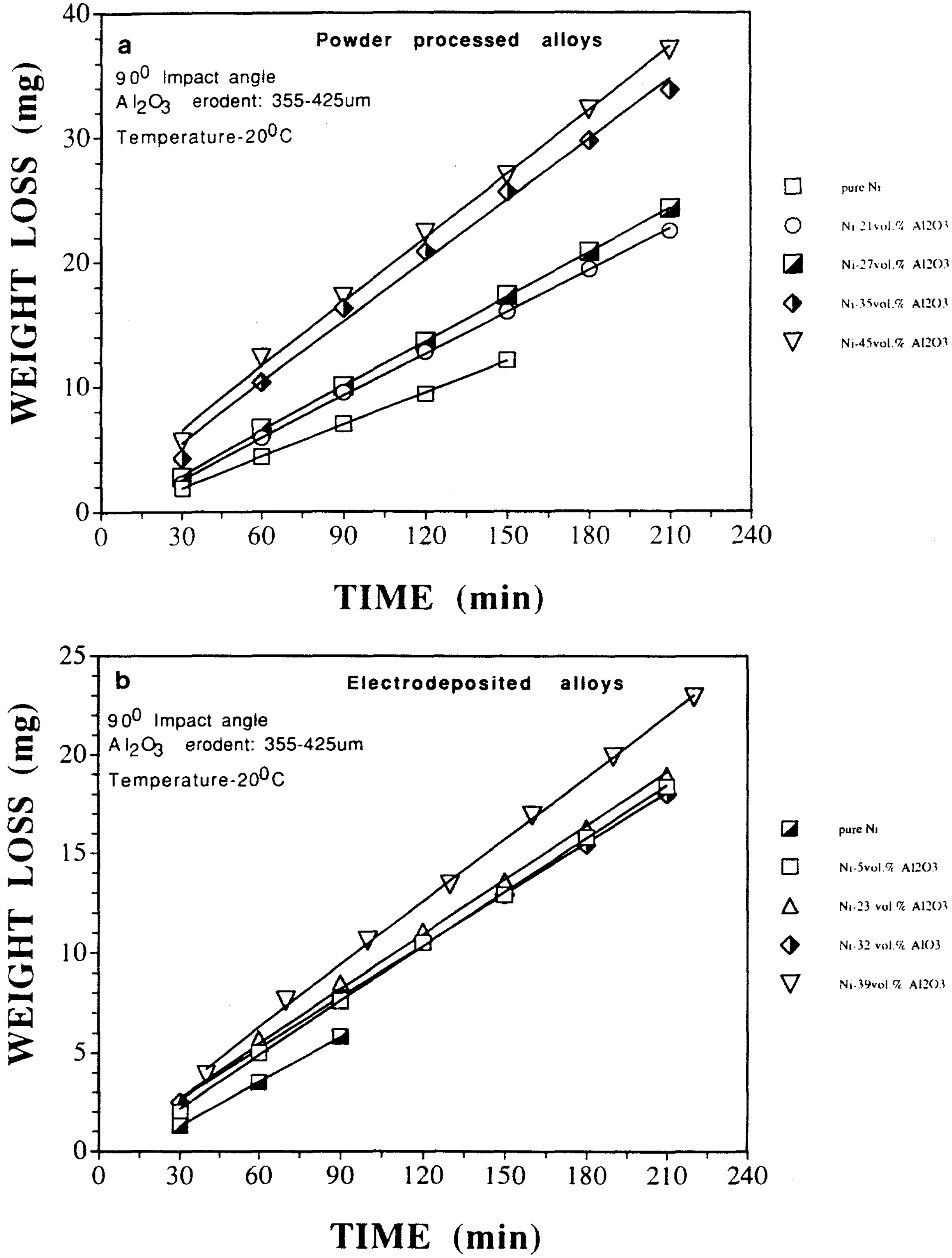

Figure 2 a and b. Erosion kinetics for the powder processed (a) and electrodeposited (b) Ni-Al_2O_3 composite alloys.

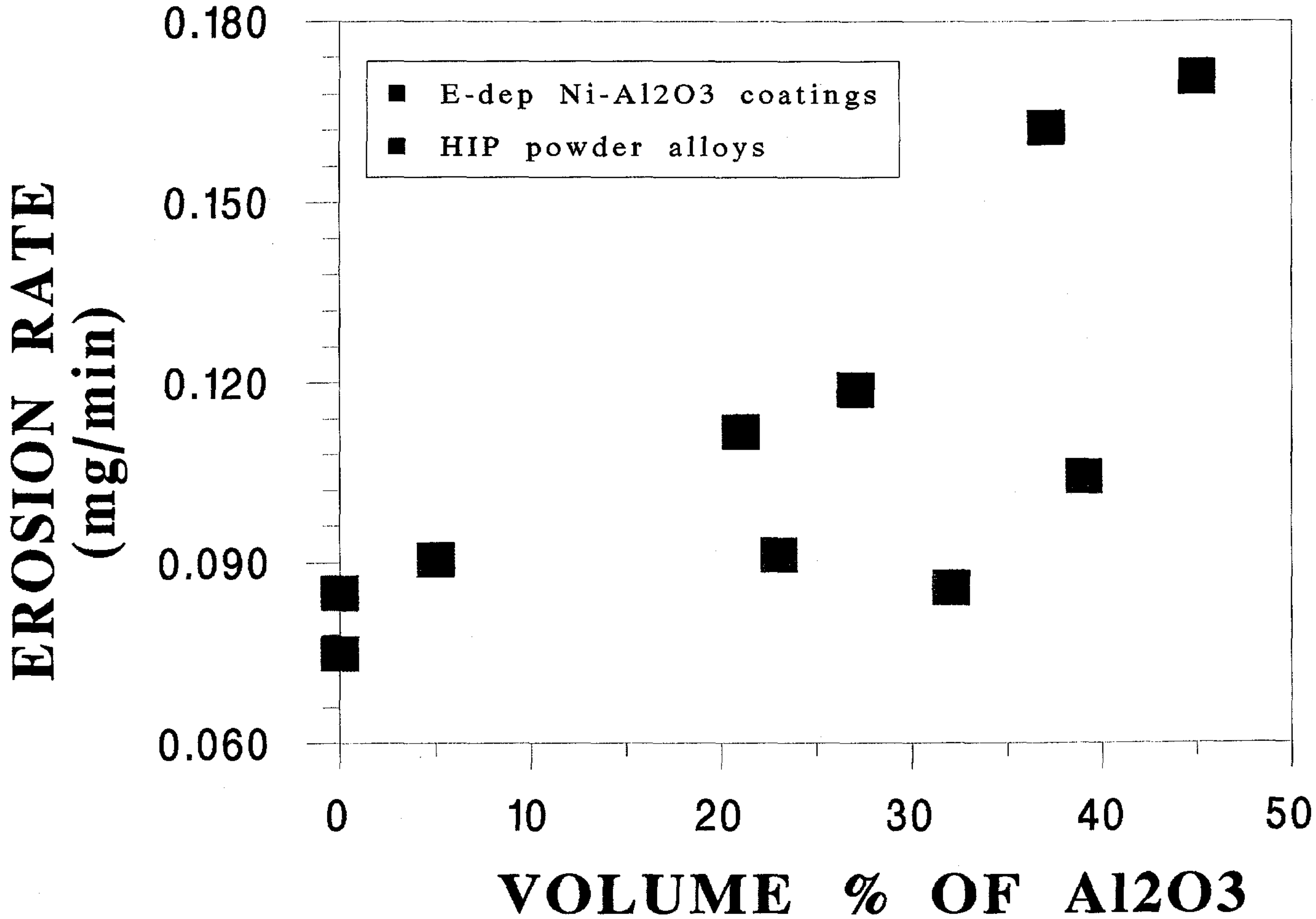

Figure 3. Effect of volume fraction of Al_2O_3 particles on erosion resistance of Ni-Al_2O_3 composite alloys.