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Robotic Weld Overlay Coatings
For Erosion Control

Progress Report Prepared For U.S.
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Quarterly Technical Progress Report
For The Period January 1994 through
March 1994

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I. EXECUTIVE SUMMARY

Research is presently being conducted to develop a criteria for selecting weld overlay coatings for erosion mitigation in Circulated Fluidized Beds. Initially, eleven weld overlay alloys were selected for erosion testing based upon a literature review. All eleven coatings were deposited on 1018 steel substrates using the plasma arc welding process [1]. Ten samples from each coating were prepared for erosion testing. The coating deposition and sample preparation procedures were described in the second quarterly report [2]. All selected coatings were erosion tested at 400°C and their erosion resistance was evaluated by determining the steady state erosion rate. In addition, the microstructure of each coating was characterized before and after the erosion tests. The results of the tests are discussed in the third quarterly report [3]. The steady state erosion rates were similar for several weld overlay coatings (Ultimet, Inconel-625, Iron-Aluminide, 316L SS, and High Chromium Cast Iron) and were considerably lower than the remaining coating evaluated. These coatings had different base materials (cobalt, iron, and nickel-base). Also, no correlations were found between room temperature microhardness of the weld overlay coatings and their erosion resistance at elevated temperature, although this criteria is often thought to be an indicator of erosion resistance. It was suggested that the coatings that showed similar erosion rates may have similar mechanical properties such as fracture strength, toughness and work hardening rates at this temperature. During the previous quarter, Iron-Aluminide, Inconel-625, and 316L SS coatings were selected for more detailed investigations based upon the preliminary erosion test results. Microhardness tests were performed on the eroded samples in order to determine

the size of the work hardened zone and the change in the coatings hardness due to erosion.

In the past quarter, microhardness tests were performed for all initially selected coatings in order to measure the size of the work hardening zone due to erosion. As a result of these tests, the size of the work hardening zone for each coating was determined. The size of the work hardening zone has been correlated to the volume erosion rate of the coatings and their hardness. Also, erosion tests at 400°C for 316L SS, Inconel-625, and Iron-Aluminide wrought materials are in progress. The erosion rates of the wrought materials will be compared with the erosion rates of the 316L SS, Inconel-625, and Iron-Aluminide weld overlays. This progress report describes the results of the research conducted since the previous progress report.

II. INTRODUCTION

The erosion of materials by the impact of solid particles has received increasing attention during the past twenty years. Recently, research has been initiated with the event of advanced coal conversion processes in which erosion plays an important role. The resulting damage, termed Solid Particle Erosion (SPE), is of concern primarily because of the significantly increased operating costs which result in material failures. Reduced power plant efficiency due to solid particle erosion of boiler tubes and waterwalls has led to various methods to combat SPE. One method is to apply coatings to the components subjected to erosive environments. Protective weld overlay coatings are particularly advantageous in terms of coating quality. The weld overlay coatings are essentially immune to spallation due to a strong metallurgical bond with the substrate material. By using powder mixtures, multiple alloys can be mixed in order to achieve the best performance in an erosive environment. However, a review of the literature revealed a lack of information on weld overlay coating performance in erosive environments which makes the selection of weld overlay alloys a difficult task [1]. The objective of this project is to determine the effects of weld overlay coating composition and microstructure on erosion resistance. These results will lead to a better understanding of erosion mitigation in CFB's.

III. EXPERIMENTAL PROCEDURE

III.1. Estimation Of The Plastic Zone Size

In order to determine the size of the deformed region beneath the eroded surface, microhardness tests were performed on a transverse section of each weld overlay coating after 100 min exposure in the erosion tester at 90° particle impact angles. As a result of the erosion, the material beneath the eroded surface may experience plastic deformation and coating hardness may increase in the vicinity of the eroded surface. A material plastic zone size can be estimated by obtaining a microhardness profile from the eroded surface into the base material. A schematic diagram of this profile is shown in Figure 1. The depth at which the hardness value equalled the base value is defined as the plastic zone size. The same experimental procedure was used for these tests as for the microhardness measurements on uneroded samples that was described in the previous reports [2,3]. However, small applied loads (10 g, 25g, 50g and 100g) were used. Application of small loads decreases the indentation size and the spacing between each indentation can be significantly decreased as a result. With this approach, even small variations in hardness with distance from the eroded surface can be detected. Three to five microhardness profiles were obtained in different locations of each coating in order to improve the statistical significance of the data. From these profiles, the size of the plastic zone for each coating was estimated.

IV. RESULTS AND DISCUSSION

The results of the microhardness tests are shown in Figures 2-12. It can be seen that for some coatings (Ultimet, Iron-Aluminide, 316L SS, Hastelloy-22, Inconel-625, and Stellite-6) hardness significantly increases in the vicinity of the eroded surface (Figures 2-7). These results indicate the formation of the work hardened zone due to particle impacts. As a result of the particle impact, the coating is plastically deformed and the dislocation density increases in the vicinity of the impact. The increase in dislocation density leads to an increase in hardness at the coating surface. The degree of work hardening may be determined by measuring the size of the plastically deformed zone. From Figures 2-7 the plastic zone size for Ultimet, Iron-Aluminide, 316L SS, Hastelloy-22, Inconel-625, and Stellite-6 weld overlays can be estimated at approximately 70um, 70um, 55um, 35um, 40um, and 20um, respectively. However, for Armacor-M, B-60, 420SS, TS-2 and High Chromium Iron coatings (Figures 8-12) no work hardening zone could be detected. These results indicate that this group of materials does not deform plastically during particle impact. Based upon these results, it can be seen that one group of coatings experienced significant plastic deformation, while another group did not deform plastically. Therefore, the erosion mechanisms might be different for these two groups of coatings. Evidence of plastic deformation due to erosion has been observed by many researches [4,5]. Usually, erosion of ductile materials is accompanied by plastic deformation and, when a critical strain is exceeded in the deformation volume underneath the eroded surface the material is detached from the surface by ductile fracture [4,5]. On the other hand, the erosion of brittle materials that do not deform plastically involves brittle fracture (i.e. chipping, cracking) after the particle impact [7]. The relationship

between plastic zone size and volume erosion rate for all the coatings is shown in Figure 13. It can be seen that materials with high ability to work harden (large plastic zone) such as Ultimet, 316L SS, Inconel-625, and Iron Aluminide exhibited low erosion rates. Materials with a low ability to work harden (small plastic zone) Armacor-M, B-60, Stellite-6, and Hastelloy-22 have higher erosion rates. These results are in agreement with those obtained by Ball [6]. However, 420 SS, High Chromium Iron and TS-2 coatings showed relatively low erosion rates in spite of the low ability to work harden. These results suggest that the erosion behavior of the coatings can not be explained only on work hardening. The factors that control erosion behavior are different for ductile and brittle materials. Apparently, for ductile weld overlays, their ability to work harden and therefore dissipate impact energy, plays a major role in erosion resistance. It was shown by Ball [6] that materials with a higher strain hardening coefficient exhibited a higher erosion resistance compared with materials with a low strain hardening coefficient. However, for brittle weld overlays, their ability to resist a brittle fracture (i.e., cracking) is a major factor that may control their erosion resistance. Therefore, materials that exhibit both high toughness and hardness may have good erosion resistance. It is clear that measurements of coating mechanical properties such as strain hardening and toughness are necessary in order to determine their effect on erosion resistance.

IV. FUTURE WORK

The mechanical properties of the weld overlays such as strain hardening coefficient, toughness, yield strength and tensile strength will be measured at 400°C. The relationship between mechanical properties and erosion resistance will be determined. In addition the erosion rates of the selected wrought materials (316L SS, Inconel-625, and Iron-Aluminide) at 400°C will be measured and compared with the erosion rates of 316L SS, Inconel-625 and Iron Aluminide weld overlays. The effect of microstructure on erosion resistance will be determined.

V. REFERENCES

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5. Sundararajan, G. and Shewmon, P.G., Wear, vol.84, pp.237-258, 1983.
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Figure 1. A Schematic diagram of the microhardness technique that was used in order to determine the size of the plastic zone due to the particles impact.

ULTIMET WELD OVERLAY COATING

Figure 2. The variation of hardness as a function of distance from the eroded surface for Ultimet weld overlay coating.

IRON ALUMINIDE WELD OVERLAY COATING

Figure 3. The variation of hardness as a function of distance from the eroded surface for Iron-Aluminide weld overlay coating.

316L SS WELD OVERLAY COATING

Figure 4. The variation of hardness as a function of distance from the eroded surface for 316L SS weld overlay coating.

HASTELLOY-22 WELD OVERLAY COATING

Figure 5. The variation of hardness as a function of distance from the eroded surface for Hastelloy SS weld overlay coating.

INCONEL-625 WELD OVERLAY COATING

Figure 6. The variation of hardness as a function of distance from the eroded surface for Inconel-625 weld overlay coating.

STELLITE-6 WELD OVERLAY COATING

Figure 7. The variation of hardness as a function of distance from the eroded surface for Stellite-6 weld overlay coating.

ARMACOR-M WELD OVERLAY COATING

Figure 8. The variation of hardness as a function of distance from the eroded surface for Armacor-M weld overlay coating.

B-60 WELD OVERLAY COATING

Figure 9. The variation of hardness as a function of distance from the eroded surface for B-60 weld overlay coating.

420 SS WELD OVERLAY COATING

Figure 10. The variation of hardness as a function of distance from the eroded surface for 420 SS weld overlay coating.

TS-2 WELD OVERLAY COATING

Figure 11. The variation of hardness as a function of distance from the eroded surface for TS-2 weld overlay coating.

HIGH CHROMIUM CAST IRON WELD OVERLAY COATING

Figure 12. The variation of hardness as a function of distance from the eroded surface for High Chromium Iron weld overlay coating.

Figure 13. Steady state volume erosion rate of weld overlay coatings as a function of plastic zone size. Erosion rates were determined for 90° impact angle.

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