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HIGH TEMPERATURE EROSION-OXIDATION BEHAVIOR OF STEELS

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Abstract: *The high temperature erosion-oxidation (E-O) behavior of steels AISI 1020, 304, 310 and 410 was determined. A test rig in which a specimen assembly was rotated through a fluidized bed of erodent particles was used to determine the E-O behavior. Alumina powder (200µm) was used as the erodent. The E-O tests were carried out in the range 25 - 600ºC, with average particle impact velocities of 6, 14 and 30 ms^{-1} at an impact angle of 90º. In the E-O tests, wastage of the steels varied with temperature and particle impact velocity (PIV). Depending on PIV, a transition in the dominant wastage mechanism occurred and the transition temperature varied with steel composition. Variation in Cr content of the steels did not affect wastage at low PIV. AISI 410 with 12% Cr revealed the lowest wastage at 30 ms^{-1} compared to AISI 304 and 310. E-O maps of the steels were prepared as a function of PIV and temperature. Low, moderate and severe wastage zones were indicated in these maps to aid selection of these steels for industrial applications.*

1. INTRODUCTION

The room temperature erosion behavior of metallic materials and ceramics has been widely studied. [1,2,7] The high temperature oxidation behavior of various metals and alloys is well documented but only limited information is available about the conjoint effect of erosion and oxidation at high temperatures.[4,8] The results of some erosion-oxidation (E-O) studies have shown synergy between erosion and oxidation, indicating that degradation caused by E-O can be greater than the sum of degradation caused by erosion and oxidation operating separately.[5,13] E-O interactions have been described in terms of regimes, often proposed as a function of temperature.[3,6,11,12] Definition of E-O regimes has varied significantly and so have the criteria for defining regime transitions.[9,10] Adequate procedures to select materials to resist E-O degradation at high temperatures are presently not available. The criteria often used in many industries to select alloys for components subject to E-O conditions are hardness, cost and availability. To provide further input to aid material selection for high temperature applications where E-O conditions prevail, studies were carried out to evaluate the E-O behavior of some commonly used steels with varying amounts of chromium. This paper presents the E-O behavior of AISI 1020, 304, 310 and 410. The E-O measurements were made in a test rig in the temperature range 25 - 600°C, using alumina particles as the erodent at average impact velocities of up to 30 ms^{-1}.

2. METHODS ND MATERIALS

E-O test specimens 0.3 x 1.0 x 5.0 cm were cut from ‘as-received’ AISI 1020, 304, 310 and 410 steel sheets, cleaned and degreased ultrasonically in acetone. An E-O test rig in which a specimen assembly was rotated through a fluidized bed of erodent particles was used. Alumina powder with particles in the size range 212-150 µm was used as the erodent. The fluidized bed of particles was obtained by pumping pre-heated air through a porous plate supporting a bed of erodent particles. Fluidization of the erodent particles was done within a furnace and the erodent impact velocity on the test specimens was controlled by a motor that rotated the specimen assembly. The E-O test specimens were weighed and fixed with AISI 310 screws to the specimen holder in the E-O test rig. The specimens were positioned at the end of a crossed specimen holder. The E-O test conditions were: (a) temperatures - R.T., 100, 200, 300, 400, 500 and 600°C; (b) erodent particle impact angle of 90° at average velocities of 6 (V1), 14 (V2) and 30 (V3) ms^{-1}. After the tests, the specimens were weighed, examined in a scanning electron microscope and their surface reaction products analyzed by EDS.

3. RESULTS AND DISCUSSION

3.1. Wastage Behavior of the Steels

Wastage or weight loss curves of the steels as a function of E-O test temperature at the 3 particle impact velocities were plotted. At V1, the wastage of the steels did not vary much up to 300° C. Above this temperature and up to 400° C all the steels except AISI 304 revealed an increase in wastage due to removal of both the surface oxide and the substrate by particle erosion. This increase in wastage was followed by a reduction in wastage at higher temperatures, indicating higher weight gain due to oxide formation than weight loss due to particle erosion. This transition took place at 400° C for AISI 310, at 450° C for AISI 1020, at 480° C for AISI 410 and at 510° C for AISI 304. At V2, the wastage behavior was quite similar to that at V1.

The wastage behavior at V3, shown in Figure 1 was quite different, compared to that at lower PIV. Significant wastage was observed at temperatures up to 100° C, and due mainly to erosion of the surface oxide and the substrate. Above this temperature, the wastage decreased due to the combined effects of new oxide formation and embedded particles. The wastage of the steels AISI 1020 and AISI 410, both Fe_3O_4 and/or Fe_2O_3 formers, increased beyond 300° C, decreased after 400° C and again increased beyond 500° C. The other two steels, AISI 304 and AISI 310, both chromium dioxide formers, did not reveal this behavior. The wastage of these steels remained almost constant up to 500° C. All the steels revealed increased wastage above 500° C. This transition, observed at 500° C at V3 is the same as that observed at 300 or 400° C at V1. This increase in wastage, which takes place at higher temperatures with increase in impact velocity has been reported in other papers.[10] The shift to lower wastage observed at 400 C or 500° C at V1 probably occurs at V3 at temperatures above 600° C. The reduction in wastage at these temperatures is due to a transition from oxidation-aided-erosion-regime to oxidation-controlled-regime. Similar observations have been also reported.[10]

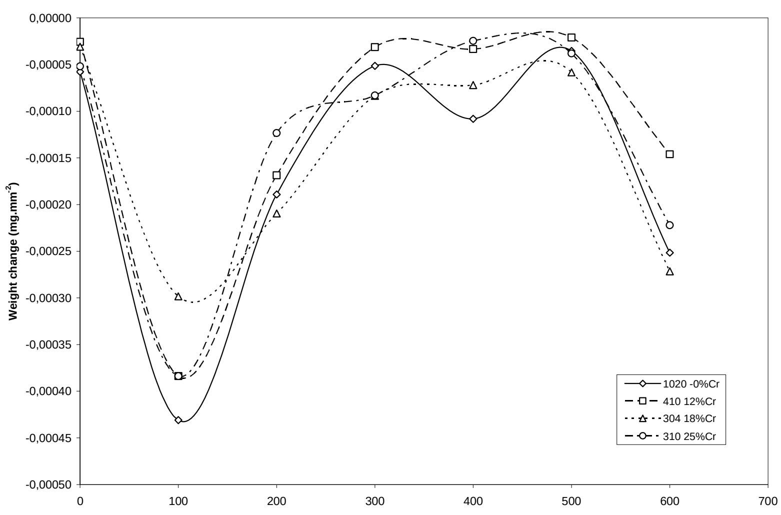

Figure 1. Wastage of the steels as a function of E-O test temperature with erosive particle impact velocity V3.

The oxide formed on the surface of AISI 1020 is a mixture of Fe_2O_3 and Fe_3O_4 at low temperatures and FeO at the higher temperatures. Fe_2O_3 is more ductile and with higher resilience to particle impact. On the other hand, FeO is brittle and easily removed upon particle impact. On the surfaces of the Cr containing steels, the oxide formed is a mixture of Fe and Cr oxides, depending on the Cr content of the steel. In the initial stages, the oxide formed is iron oxide and subsequently, the layers close to the metal-oxide interface consist of Cr_2O_3. The external iron oxide layer is easily removed by particle impact leaving behind a thin layer of Cr_2O_3. This process explains the reduced wastage at temperatures above 500° C. At even higher temperatures, the increase in wastage can be attributed to removal of the thin Cr_2O_3 layer along with the metallic substrate. The E-O regime transitions were observed. In the case of AISI 1020 it shifted from 450° C at V1 to 500° C at V2 to > 600° C at V3. That of AISI 410 shifted from 500° C at V1 to > 600° C for V3. The transition temperatures for AISI 304 did not shift from 500° C with PIV from V1 to V2. The transition temperature at V3 was > 600° C. In the case of AISI 310 it shifted from 400° to 510° to >600° C with increase in PIV from V1 to V2 to V3.

The surfaces of all the steel specimens E-O tested at the various temperatures for 5 h and at the different PIV were examined in a SEM and specific regions were analyzed. The main surface features were: (a) embedded alumina particles; (b) erosion of the substrate and the specimen surfaces were coherent with the wastage curves of the steels; (c) platelet formation on steels tested at 600° C and at V3.

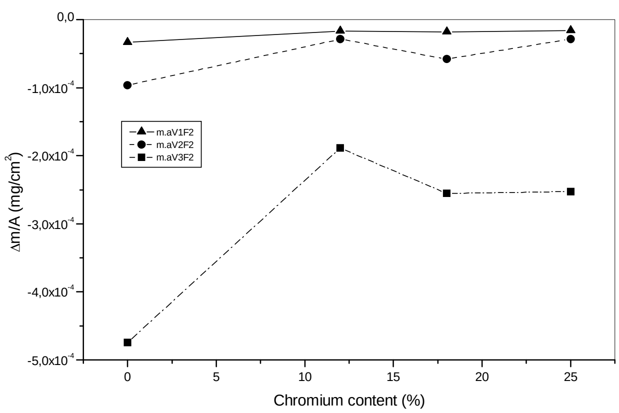

Figure 2. Wastage curves of the steels E-O tested at 500° C for 5h as a function of Cr content.

3.2. Effect of Cr Content on Wastage of the Steels

Figure 2 shows the wastage of the steels E-O tested for 5 h at 500° C as a function of chromium content in the steel. At V1, the wastage did not vary with Cr content of the steel. At V2, the wastage of all the steels increased, but decreased with the amount of Cr in the steel. The difference in the wastage of the steels AISI 410, 304 and 310 with 12, 18 and 25 % Cr was small. At V3, the wastage was significant. The Cr containing steels revealed reduced wastage. However, AISI 410 with 12% Cr revealed the lowest wastage compared to AISI 304 and 310, due probably to formation of martensitic phases and chromium carbide precipitates in AISI 410.

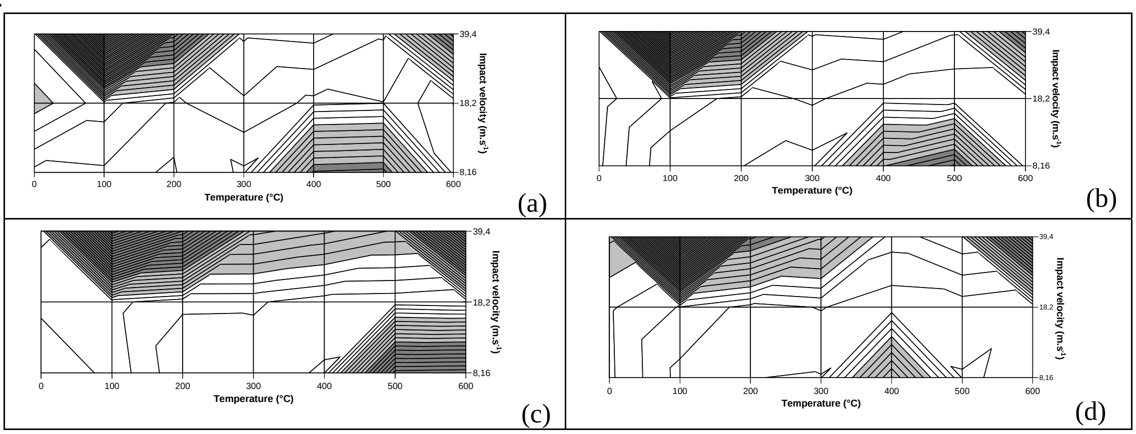

Figure 3. E-O wastage maps of (a) AISI 1020; (b) AISI 410; (c) AISI 304; (d) AISI 310.

3.3. Erosion-Oxidation Maps

Values to define low, moderate and high wastage were specified as: up to - 4.0 x 10^{-5} , between - 4,0 x 10^{-5} and -1,0 x 10^{-4}, more than -1,0 x 10^{-4} respectively. These values were based on data from literature about acceptable levels of degradation of industrial components exposed to aggressive atmospheres. On the basis of these values, E-O maps were created as a function of temperature and erosive particle impact velocity in E-O conditions for the different steels. Figure 3 shows the E-O maps of the four steels and the white, light grey and dark grey areas indicate low, moderate and severe wastage zones respectively.

4. CONCLUSIONS

1. At V1 and V2, overall wastage was low. The variations in wastage were due to weight loss from oxide and surface erosion, weight gain due to oxide formation and weight gain due to embedded particles.
2. At V3, marked wastage was observed. The wastage of the Fe_3O_4/Fe_2O_3 formers, AISI 1020 and 410, increased at temperatures above 300° C, decreased beyond 400° C and once again increased above 500° C. Wastage of the chromium dioxide formers, AISI 304 and 310, remained almost constant up to 500° C. Above this temperature, all the steels revealed increases in wastage.
3. The E-O transition temperatures of the steels as a function of PIV were determined.
4. Variation in chromium content of the steels did not affect wastage at V1 and V2. At V3, the wastage of the steels with Cr decreased. AISI 410 revealed the lowest wastage, due probably to the formation of martensitic phases and carbide precipitates in AISI 410.
5. Wastage values in mg.mm^{-2} to define low, moderate and severe wastage were specified and based on these values E-O maps were prepared as a function of PIV and temperature. Low, moderate and severe wastage zones were indicated in these maps.

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