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April 1984

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**THE EFFECT OF TEST VARIABLES ON THE PLATELET
MECHANISM OF EROSION**

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INTRODUCTION

The platelet mechanism of erosion of ductile metals has been studied in this laboratory over the past several years. Reference 1 is a recent paper that describes the mechanism and provides supporting data for it. Since the principal data used to develop this mechanism to describe the gas-solid particle impact erosion of ductile metals was obtained at relatively low velocities around 30 m/s (100f/s), and impingement angles greater than $\alpha=30^\circ$, an investigation has been conducted to determine whether the mechanism was still applicable at higher velocities and lower impingement angles. The test equipment used ² has a practical upper limit of velocity of 130 m/s (400f/s) and so the erosion rates of steel and aluminum alloys were determined over a range of velocities from 30 to 130 m/s. While the higher velocity is still considerably below that which occurs in turbine components, ~300 m/s, is still high enough to cause more than an order of magnitude increase in erosion rate in the velocity range investigated. The geometry of the erosion tester permits a minimum impingement angle of $\alpha=20^\circ$ to be used.

The principal question that existed regarding the applicability of the platelet mechanism to higher velocity particles was whether the increased momentum of the particles could affect their angular momentum of inertia to the degree that they would maintain their initial angular position in contact with the target metal surface over a relatively long distance, resulting in a cutting action. A shallower impingement angle could also result in a cutting action. The platelet mechanism is based upon a short contact time and traversed length along the specimen

surface that results in an extrusion-forging action that forms and extends the platelets. Also the platelet mechanism depends on large plastic deformation and resultant surface heating ^{3, 4} which could be adversely affected by a significant increase in particle velocity. Another test variable that could affect the particle's angular moment of inertia is its size, particularly large size particles. The effect of this variable was also investigated.

TEST DESCRIPTION

A room temperature erosion tester was used that is described in Reference 2. Three sets of experiments were conducted. In the first set, 300 grams of 250 μ m SiC particles were used to erode 1020 steel, 304SS and 1100-0 aluminum. The specimens were 6.4x1.9x0.3cm and were polished prior to testing with 600 grit SiC. Velocities of 30, 60, 90 and 130 m/s were used at impingement angles of $\alpha=30^\circ$ and 90° . The particle velocities were determined using the rotating disc method. In the second set of experiments 1020 steel, 4340 steel and 304SS were eroded with 300g of 100 μ m Al₂O₃ particles at velocities of 30, 60 and 90 m/s at impingement angles of $\alpha=30^\circ$ and 90° . The Al₂O₃ particles were somewhat less angular than the SiC particles and considerably smaller in size. Weight losses were determined using an analytical balance which measured weight to 0.0001g. The hardness of the different alloys tested are listed in Tables 1 and 2.

In the third set of experiments 1018 steel and 304SS were eroded with 250-300 μ m SiC particles at impingement angles from $\alpha=20^\circ$ to 90° and with Al₂O₃ particles of 50, 100 and 140 μ m dia at velocities from 15

to 130 m/s. In this series of tests incremental erosion rates were obtained to determine the shape of the erosion rate curve as a function of quantity of particles.

RESULTS AND DISCUSSION

Steady State Erosion Rates:

The steady state erosion rates of the alloys eroded with SiC particles are listed in Table 1. The steady state erosion of the alloys eroded with the smaller size Al_2O_3 particles are listed in Table 2. All weight losses were normalized to account for the different densities of the alloys tested by dividing the weight loss by the density of the alloy. This resulted in the determination of the volume of material loss per gram of eroding particles.

It can be seen in Table 1 that more volume of material was eroded for the aluminum than from the steel alloys. The difference was most pronounced at the lowest velocity. The two steel alloys eroded at a similar rate except at the highest velocity where the mild steel eroded at a lower rate than the 304SS. This difference at the highest velocity used in the experiment revised a trend observed at lower velocities where 304SS eroded at a lower rate than 1020 steel calculated on g/g basis.⁵

In Table 2, the erosion rates for the three steels tested were comparable at all of the particle velocities. At the 60 and 90 m/s particle velocities, the erosion rates were lower than for the same alloys eroded with SiC particles. This behavior is in accordance with the observed in Reference 6 because of the somewhat more angular shape of the SiC particles compared to the Al_2O_3 particles. However, an

incongruity exists at the lowest velocity utilized. At 30 m/s the Al_2O_3 particles removed more volume of material than the SiC particles for the 1020 and 304SS. The reason for this reversal in behavior is not known.

Microstructures of Eroded Surfaces:

SiC Erodent

All of the specimens tested at all conditions had the typical platelet formations on their surfaces observed in the earlier work.¹ The 1020 steel and 304SS eroded with the SiC particles had essentially the same appearance at all test conditions. Figure 1 shows the surface of the 1020 steel after erosion. It can be seen that the texture of the eroded surface consists of shallow craters and platelets at various stages of development. There is essentially no difference in the appearance of the surface texture between the specimens eroded at 30 m/s and 130 m/s and at 30° and 90° impingement angles.

The effect of the erodent particle velocity is seen in Figure 2. The sizes of the craters and platelets on the 1020 steel specimen eroded at 130 m/s are considerably larger than those eroded at 30 m/s. The increased kinetic energy of the particles moving at the higher velocity cause deeper craters and larger platelets to form. Table 1 shows the effect of the larger platelets on the erosion rate. An increase in the 1020 steel erosion rate of 1-1/2 orders of magnitude occurred between 30 m/s and 130 m/s particle velocities.

Figures 3 and 4 show the surface and cross section of the 304SS eroded at velocities of 30 and 130 m/s. The principal difference in

surface appearance between the low and high velocities is the size of the craters in the $\alpha=30^\circ$ impingement angle tests which are longer in the 130 m/s specimens. The basic orientation of the craters of the $\alpha=30^\circ$ eroded specimens is along the direction of the impacting particles as shown by the arrows on the figure. There is no strong orientation of the platelets. There is no readily apparent difference in the surface appearance of the $\alpha=90^\circ$ specimens at the two test velocities.

Comparing the $\alpha=30^\circ$ and 90° specimens shows that the same platelet mechanism occurs at both angles. Longer craters are seen on the $\alpha=90^\circ$ specimen compared to the $\alpha=30^\circ$ specimen at the low velocity. At the 130 m/s velocity, there is no distinct difference, either in the surface photos in Figure 3 or in the cross section photos in Figure 4. This relates to the relatively small difference in the erosion rates of the two specimens listed in Table 1.

Figures 5 and 6 show the surface and cross sections, respectively, of the 1100-0 aluminum eroded specimens. The orientation of the platelets and the craters are along the direction of the impacting particles in the $\alpha=30^\circ$ specimens. This can be seen most easily in the 90 m/s specimen surface in the lower left corner of Figure 5. The $\alpha=90^\circ$ specimens have a random orientation of the platelets and craters. There is not a significant difference in the size of the platelets at the two test velocities at $\alpha=90^\circ$. Comparing the eroded surfaces of the three metals eroded with SiC particles, Figures 1, 3 and 5, there does not appear to be a major difference in their textures. The 1100-0 aluminum appears to have a somewhat more textured

surface.

Figure 6 shows the cross section of the eroded surface of the 1100-0 Al at the same magnification for the specimens eroded at $V=30$ and 90 m/s. As was observed for the 1020 steel there is a major difference in the size of the platelets and the depth of the craters. This difference accounts for the order of magnitude increase in the erosion rate from $V=30$ m/s to $V=90$ m/s. The absence of a significant difference in the size of the platelets in Figure 4 for the 304SS relates to the comparatively small difference in erosion rates as a function of impingement angle.

Comparing the eroded surface cross sections of the 1020 steel and 1100-0 aluminum, Figures 2 and 6, shows the effect of higher velocity, 130 m/s, particles on the softer, more extrudeable 1100-0 aluminum. The sizes of the craters and platelets are much larger in the aluminum specimen than in the 1020 steel specimens. Comparing the two materials at the lower velocity, 30 m/s, there does not appear to be much difference in the texture of the two surfaces. It is to be noted that a classic shaped platelet is shown in the left hand side of the left photo in Figure 2. It's cross section is similar to that of a flat mushroom with a stem that attaches the platelet to the base metal.

Al_2O_3 erodent

The smaller Al_2O_3 particles developed a finer textured platelet-crater structure than occurred on the specimens eroded by the SiC particles. Figure 7, which shows the surface of the 1020 steel eroded by the alumina, should be compared with Figure 1 for the SiC particle at $V=30$ m/s specimens to see this difference. The smaller particles

produced textures that did not differ significantly at low and high erosion velocities or at $\alpha=30^\circ$ and 90° when viewed from the surface. All four photos in Figure 7 appear very similar in appearance. However, the cross section view of the 1020 steel in Figure 8 shows that there was a significant difference in the size of the platelets at the $\alpha=30^\circ$ and 90° impingement angles. This difference is consistent for all of the specimens tested.

The 304SS behaved very similar to the 1020 steel. Figures 9 and 10 show the eroded surface and the cross section, respectively. The textures shown in Figure 9 are about the same for all four photos, with a platelet and crater size that is smaller than those seen in Figure 3.

The cross sections shown in Figure 10 for the 304SS shows the same occurrence of larger platelets for the higher velocity erosion test. There is no basic difference in the detailed nature of the platelets formed at different velocities except for their size.

The annealed 4340 steel eroded surface is shown in Figure 11. The orientation of the craters in the $\alpha=30^\circ$ specimens is along the direction of the impacting particles' trajectories, as seen in other specimens tested at $\alpha=30^\circ$. The size of the craters was larger in the specimens eroded at $V=90$ M/s than in the specimens eroded at $V=30$ m/s. The crater size difference appears to be the primary difference that occurs as the result of the velocity increase. Figure 12 of the cross section of the eroded surface shows that somewhat larger platelets are formed at the higher velocity. The difference is not as great as that which occurred on the aluminum eroded at the same two velocities with SiC particles, shown in Figure 6. Referring to Tables 1 and 2, the

relative difference in platelet sizes correlates well with the differences in erosion rates. The 4340 steel erosion rate increase was 1/2 that of the increase which occurred in the 1100-0 Al in going from a velocity of 30 m/s to 90 m/s. The much greater difference in the relative size of the platelets formed on the aluminum at the low and high velocities, compared to the differences that occurred in the 4340 steel, Figure 12, relates, in part, to their erosion rates. Comparing the erosion rates of the harder 4340 steel with the softer 1020 and 304SS in Table 2, it can be seen that their hardness has essentially no effect on their erosion rates at the three particle velocities used.

EMBEDMENT

Evidence of embedment of erodent particles in the surface of the target material was observed during the investigation. Figure 13 shows three typical examples of chips of SiC embedded in aluminum and 304SS eroded surfaces. The size of each chip is a small fraction of the starting particle size of 250 μ m. This indicates that small protruding portions of erodent particles that contact the target metal surface in such a way as to place a high bending load on the protruding portion, exceeding its fracture strength, are responsible for the embedment which occurred in the alloys tested. The number of such fragments observed on the eroded surfaces examined was very small. An indication of the extent of the embedment of SiC particles can be seen in Figure 2 in the right hand side photo. Under the crater on the right side of the photo can be seen some evidence of chips of SiC. Under other circumstances, such as the use of weaker erodent particles⁶ or testing

at elevated temperatures,⁸ the amount of embedded material is considerably greater.

INCREMENTAL EROSION RATES

The nature of the incremental erosion rate curve near the time of initiation of erosion was investigated to determine what occurs when the early platelets are being formed on the eroding surface. The velocity of the particles as well as their impingement angle and size were varied. In previous work at this laboratory^{1, 2} incremental erosion rate curve determinations were made using 10-30g increments of erodent. In this study, increments of 1-2g of erodent were used for the first 10g of erodent and 5g increments were used up to 30g.

Effect of Impingement Angle

It was determined that an incremental erosion rate peak occurred at all test conditions near 20g of particles. Figure 14 plots the incremental erosion rates of 1018 steel at 3 impingement angles $\alpha=20^\circ$, 30° , 90° . The peak rate can be seen on all three curves at about 20g of particles. The peak rate is followed by a sharp decrease in the rate to a level slightly below the steady state level and then an increase in rate up to the steady state rate. The steady state erosion rates are highest at $\alpha=30^\circ$ and lowest at $\alpha=90^\circ$ as expected. The consistence of the incremental erosion rates in the steady state region is evident in all three curves. The general shape of all three curves is representative of the platelet mechanism of erosion wherein an initial threshold period occurs with no measurable erosion, followed by an increasing rate up to the initial peak rate and then down to a final

steady state rate, as discussed in Reference 3.

It is interesting to note that even at shallow impingement angles that are less than the peak erosion rate angle, the shape of the curve is the same. This indicates that the platelet mechanism is still the active mechanism. It was thought that possibly at the shallow impingement angles the micro-machining mechanism might have become the major mechanism.

Figure 15 further verifies that platelet formation dominates at less than the peak impingement angle. It also contributes to understanding why there is a peak erosion rate near 20g of particles. Both photos show the presence of platelets and shallow craters in tests carried out at $\alpha=20^\circ$. However, there is a significant difference in the surface texture of the top photo which was taken at the peak erosion rate shown in Figure 14 and the bottom photo which was taken at steady state erosion. The surface at the peak incremental erosion rate consists of relatively large craters and platelets compared to the smaller size of the craters and platelets at the steady state erosion rate. A stereo pair of each of the surfaces showed the larger platelets at peak erosion to be protruding much higher above the surface than the smaller platelets at steady state erosion. Thus, at the peak erosion condition prior to reaching steady state erosion, the platelets are both larger and more vulnerable to being knocked off the surface than are the platelets at steady state erosion. This same pattern was also observed on specimens tested at $\alpha=30^\circ$ and 90° .

As erosion approaches the steady state rate and the full texture of the eroding surface is achieved, some platelets are mashed down into

nearby craters, thereby decreasing their vulnerability and making them more difficult to remove from the surface. The number that are knocked off the surface by an increment of eroding particles thereby decreases. The mashed down platelets will generally be removed as the result of their fracture into pieces by the impacting particles rather than the whole platelet being removed by the fracture of its attachment stem as occurs more often near the beginning of the erosion process. An example of the latter configuration is shown in the left hand photo in Figure 2 which shows a well formed platelet with its attachment stem intact. This sequence of events explains the shape of the curves in Figure 14.

Effect of Velocity

A series of tests was carried out at the $\alpha=20^\circ$ shallow impingement angle at several velocities to determine whether the predominant erosion mechanism of platelet formation and removal would be replaced by a microcutting mechanism as the velocity increased. Figure 16 shows that the incremental erosion rate curves for 1018 steel had the same pattern at particle velocities of 15, 30, 45 and 130 m/s. The initial peak erosion rates occurred near 20g of particles as they did in Figure 14. The steady state erosion rates were constant and related directly to the particle velocity. Even at the high velocity of 130 m/s the same pattern of the incremental erosion rate curve occurred.

Effect of Particle Size

Figure 17 is a plot of the incremental erosion rate of 304SS vs the weight of SiC impacting particles of three different sizes. The first weighable loss of material occurs at different erosion rates for

each particle size with the largest particle size having the lowest initial erosion rate. The incremental erosion rate curves for the three particle sizes all reach an initial peak erosion rate at the same incremental erodent weight, 35g. Subsequent increments of erodent causes lower erosion rates until the same steady state erosion rate is reached for all three sizes of erodent at about 1/2 the peak rate. An incremental erosion rate test was carried out on 304SS using 40 μ m size particles at V=30 m/s and $\alpha=90^\circ$. No measurable erosion occurred until 200g of particles had impacted the surface and an incremental erosion rate of 0.17×10^{-4} g/g was measured after 300g of erodent were used. The independence of the steady state erosion rate for particle sizes above 100 μ m and the decrease in rate at the smaller particle size used agrees with the results of earlier work⁷ where the erosion rate was determined to be independent of the particle size above $\sim 100\mu$ m. Microscopic examination of the eroded surfaces in this test series indicated that the platelet mechanism of erosion occurred on all of the specimens.

The curves in Figure 17 can be explained using the platelet mechanism of erosion¹ in the following manner. As the initial particles strike the surface, they create craters and extrude up platelets. The larger the erodent particle is, the fewer are the number that strike the surface for any weight increment of particles, but the larger are the size of the platelets they extrude up. The larger extrusion force that occurs is due to the greater mass of the larger particles. For a given weight of impacting particles the larger platelets are fewer in number than the smaller platelets extruded by many more smaller size SiC particles. The small number of larger

platelets begin to fracture and be removed from the surface in weighable quantities when their total weight is estimated to be less than that of the weight of the much greater number of smaller platelets. Hence, the initial measureable weight loss is lowest for the largest, 600 μ m particles and highest for the smallest, 100 μ m particles. The total weight of erodent particles when measurable erosion weight loss occurs in all three cases is near the same 10 to 20g.

At steady state erosion, all three particles sizes cause the same rate of erosion to occur for a given weight increment of particles. By the time that the full eroded texture is reached on the surface of a ductile metal specimen, the sizes of platelets or pieces of platelets that can be knocked off the surface is essentially constant. The size of the particles striking the surface, at least within the range of 100-600 μ m used in this investigation can not change the size of the pieces of platelets removed. The erosion rate is related to the total kinetic energy of all of the particles striking the surface which is a function of their total weight and not their number.

The less angular Al₂O₃ erodent particles in three different particle sizes were used to erode 304SS in order to determine whether particles with less erosivity as the result of shape and size would cause a different pattern of erosion to occur at the beginning of the erosion test. Figure 18 is a plot of the incremental erosion rate of 304SS for the three particle sizes used. It can be seen that the same peak erosion rate occurred near the beginning of the test as was observed for the SiC particles. The particle size effect observed in

Figure 17 for the SiC particles at the beginning of the tests where the largest size particles resulted in the lowest first measurable erosion rate was not observed for these generally smaller, less angular particles. The particle size effect documented by Tilly⁷ can be readily seen in Figure 18. The 50 μ m size particles caused less than half the steady state erosion rate of the 140 μ m particles.

CONCLUSIONS

1. Ductile metals subjected to the impact of small solid particles in gas streams lose material by the platelet mechanism of erosion over a range of velocities from 30 to 130 m/s.
2. Higher particle velocities cause larger platelets and deeper craters to be generated which results in greater material loss.
3. The softer, more extrudeable 1100-0 Al had larger platelets form than the steel alloys at the same erosion conditions.
4. Platelet formation occurs at both 30° and 90° impingement angles, resulting in the same type of microtexture. At 30° the platelets and craters are generally strained in the direction of particle impact. At 90° they are randomly oriented.
5. The incremental erosion rate curve for 304SS have an initial peak erosion rate that is twice the steady state rate for a range of erodent particle sizes from $100\mu\text{m}$ to $600\mu\text{m}$. The initial, measurable erosion rates, erosion rate peaks and the shape of the curves can all be explained using the platelet mechanism of erosion.
6. Embedment of small chips of SiC erodent material that break off the much larger erodent particles occurs over a very small percentage of an eroded surface.

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FIGURES

1. Surface of 1020 steel eroded by SiC particles at $V=20, 130$ m/s.
2. Cross section of 1020 steel eroded by SiC particles at $V=30, 130$ m/s.
3. Surface of 304SS eroded by SiC particles at $V=30, 130$ m/s.
4. Cross section of 304SS eroded by SiC particles at $V=30, 130$ m/s.
5. Surface of 1100-0 Al eroded by SiC particles at $V=30, 130$ m/s.
6. Cross section of 1100-0 Al eroded by SiC particles at $V=30, 130$ m/s.
7. Surface 1020 steel eroded by Al_2O_3 particles at $V=30, 90$ m/s.
8. Cross section of 1020 steel eroded by Al_2O_3 particles at $V=30, 90$ m/s.
9. Surface of 304SS eroded by Al_2O_3 particles at $V=30, 90$ m/s.
10. Cross section of 304SS eroded by Al_2O_3 particles at $V=30, 90$ m/s.
11. Surface of 4340 steel eroded by Al_2O_3 particles at $V=30, 90$ m/s.
12. Cross section of 4340 steel eroded by Al_2O_3 particles at $V=30, 90$ m/s.
13. Embedded SiC particles in eroded surfaces.
14. Incremental erosion rates of 1018 steel at $\alpha=20^\circ, 30^\circ, 90^\circ$.
15. Surface of eroded 1018 steel at incremental peak and steady state erosion rates.
16. Incremental erosion rates of 1018 steel at $V=15, 30, 45, 130$ m/s.
17. Incremental erosion rates of 304SS at 3 particle sizes of SiC erodent.
18. Incremental erosion rates of 304SS at 3 particle sizes of Al_2O_3 erodent.

TABLE I

Steady State Erosion Rate $\text{cm}^3/\text{g} \times 10^{-5}$ 300 g of 250 μm SiC Particles									
Material	Hard- ness VHN	$\alpha = 30^\circ$				$\alpha = 90^\circ$			
		30 m/s	60 m/s	90 m/s	130 m/s	30 m/s	60 m/s	90 m/s	130 m/s
1020 Steel	135	0.86	4.10	9.10	9.50	0.32	1.75	4.54	5.50
304SS	198	0.72	3.53	9.97	13.10	0.38	2.31	7.50	10.40
Al-1100	42	1.6	6.3	13.3	19.34	0.94	3.40	9.92	12.40

TABLE II

Steady State Erosion Rate $\text{cm}^3/\text{g} \times 10^{-5}$ 300g of 100 μm Al_2O_3 Particles							
Material	Hard- ness VHN	$\alpha = 30^\circ$			$\alpha = 90^\circ$		
		30 m/s	60 m/s	90 m/s	30 m/s	60 m/s	90 m/s
1020 Steel	135	0.46	1.31	2.82	0.28	0.76	1.33
304SS	198	0.25	1.15	3.11	0.12	0.76	2.22
4340	290	0.50	1.80	3.02	0.25	1.23	2.51

$\alpha = 30$
 $v = 30 \text{ m/s}$
 $E = 0.20 \times 10^{-5} \text{ cm}^3/\text{g}$

$\alpha = 90$
 $v = 30 \text{ m/s}$
 $E = 0.08 \times 10^{-5} \text{ cm}^3/\text{g}$

$\alpha = 30$
 $v = 130 \text{ m/s}$
 $E = 9.50 \times 10^{-5} \text{ cm}^3/\text{g}$

$\alpha = 90$
 $v = 130 \text{ m/s}$
 $E = 5.58 \times 10^{-5} \text{ cm}^3/\text{g}$

Fig. 1. Surface of 1020 steel eroded by SiC particles at $V=30, 130 \text{ m/s}$

XBB 8210-9327A

$\alpha = 90$
 $v = 30 \text{ m/s}$

10 μm

$\alpha = 90$
 $v = 130 \text{ m/s}$

10 μm

XBB 831-430

1020 Steel
 250 μm SiC

Fig. 2. Cross section of 1020 steel eroded by SiC particles at $V=30, 130 \text{ m/s}$

$\alpha = 30$
 $v = 30 \text{ m/s}$
 $E = 0.10 \times 10^{-5} \text{ cm}^3/\text{g}$

$\alpha = 90$
 $v = 30 \text{ m/s}$
 $E = 0.05 \times 10^{-5} \text{ cm}^3/\text{g}$

$\alpha = 30$
 $v = 130 \text{ m/s}$
 $E = 13.10 \times 10^{-5} \text{ cm}^3/\text{g}$

$\alpha = 90$
 $v = 130 \text{ m/s}$
 $E = 10.40 \times 10^{-5} \text{ cm}^3/\text{g}$

Fig. 3. Surface of 304SS eroded by SiC particles
 at $V=30, 130 \text{ m/s}$

XBB 8210-9328A

$\alpha = 30^\circ$
 $v = 130 \text{ m/s}$

$10 \mu\text{m}$

$\alpha = 90^\circ$
 $v = 130 \text{ m/s}$

$10 \mu\text{m}$

XBB 8210-9330A

304 SS
 250 μm SiC

Fig. 4. Cross section of 304SS eroded by SiC particles at $V=30, 130 \text{ m/s}$

$\alpha = 30$
 $v = 30 \text{ m/s}$
 $E = 1.60 \times 10^{-5} \text{ cm}^3/\text{g}$

10 μm

$\alpha = 90$
 $v = 30 \text{ m/s}$
 $E = 0.94 \times 10^{-5} \text{ cm}^3/\text{g}$

10 μm

$\alpha = 30$
 $v = 30 \text{ m/s}$
 $E = 13.3 \times 10^{-5} \text{ cm}^3/\text{g}$

10 μm

Al - 1100
250 μm SiC

$\alpha = 90$
 $v = 90 \text{ m/s}$
 $E = 9.92 \times 10^{-5} \text{ cm}^3/\text{g}$

10 μm

XBB 831-949

Fig. 5. Surface of 1100-0 Al eroded by SiC particles at $V=30, 130 \text{ m/s}$

$\alpha = 30$
 $v = 30 \text{ m/s}$

10 μm

$\alpha = 30$
 $v = 90 \text{ m/s}$

10 μm

XBB 831-950

Al - 1100
 250 μm SiC

Fig. 6. Cross section of 1100-0 Al eroded by
 SiC particles at $V=30, 130 \text{ m/s}$

$\alpha = 30$
 $v = 30 \text{ m/s}$
 $E = 0.46 \times 10^{-5} \text{ cm}^3/\text{g}$

10 μm

$\alpha = 90$
 $v = 30 \text{ m/s}$
 $E = 0.28 \times 10^{-5} \text{ cm}^3/\text{g}$

10 μm

$\alpha = 30$
 $v = 90 \text{ m/s}$
 $E = 2.82 \times 10^{-5} \text{ cm}^3/\text{g}$

10 μm

1020 Steel
100 μm Al_2O_3

$\alpha = 90$
 $v = 90 \text{ m/s}$
 $E = 1.33 \times 10^{-5} \text{ cm}^3/\text{g}$

10 μm

XBB 831-948

Fig. 7. Surface 1020 steel eroded by Al_2O_3 particles at $V=30, 90 \text{ m/s}$

$\alpha = 30$
 $v = 30 \text{ m/s}$

10 μm

$\alpha = 30$
 $v = 90 \text{ m/s}$

10 μm

XBB 831-951

1020 Steel
 100 μm Al₂O₃

Fig. 8. Cross section of 1020 steel eroded by
 Al₂O₃ particles at V=30, 90 m/s

$\alpha = 30$
 $v = 30 \text{ m/s}$
 $E = 0.25 \times 10^{-5} \text{ cm}^3/\text{g}$

$\alpha = 90$
 $v = 30 \text{ m/s}$
 $E = 0.04 \times 10^{-5} \text{ cm}^3/\text{g}$

$\alpha = 30$
 $v = 90 \text{ m/s}$
 $E = 3.11 \times 10^{-5} \text{ cm}^3/\text{g}$

$\alpha = 90$
 $v = 90 \text{ m/s}$
 $E = 2.22 \times 10^{-5} \text{ cm}^3/\text{g}$

XBB 831-952

Fig. 9. Surface of 304SS eroded by Al_2O_3 particles at $V=30, 90 \text{ m/s}$

$\alpha = 30$
 $v = 30 \text{ m/s}$

10 μm

$\alpha = 30$
 $v = 90 \text{ m/s}$

10 μm

XBB 831-953

304 SS
 100 μm Al_2O_3

Fig. 10. Cross section of 304SS eroded by Al_2O_3 particles at $V=30, 90 \text{ m/s}$

$\alpha = 30$
 $v = 30 \text{ m/s}$
 $E = 0.05 \times 10^{-5} \text{ cm}^3/\text{g}$

$\alpha = 90$
 $v = 30 \text{ m/s}$
 $E = 0.25 \times 10^{-5} \text{ cm}^3/\text{g}$

$\alpha = 30$
 $v = 90 \text{ m/s}$
 $E = 3.02 \times 10^{-5} \text{ cm}^3/\text{g}$

$\alpha = 90$
 $v = 90 \text{ m/s}$
 $E = 2.51 \times 10^{-5} \text{ cm}^3/\text{g}$

XBB 831-954

Fig. 11. Surface of 4340 steel eroded by Al_2O_3 particles at $V=30, 90 \text{ m/s}$

$\alpha = 30$
 $v = 30 \text{ m/s}$

10 μm

$\alpha = 30$
 $v = 90 \text{ m/s}$

10 μm

XBB 831-955

4340
 100 μm Al_2O_3

Fig. 12. Cross section of 4340 steel eroded
 by Al_2O_3 particles at $V=30, 90 \text{ m/s}$

Al - 1100
250µm SiC
 $\alpha = 90$
 $v = 130$ m/s

5µm

Al - 1100
250µm SiC
 $\alpha = 30$
 $v = 130$ m/s

5µm

304 SS
250µm SiC
 $\alpha = 90$
 $v = 130$ m/s

3µm

Fig. 13. Embedded SiC particles in eroded surfaces

XBB 831-956

Fig. 14. Incremental erosion rate curves for 1018 steel at $\alpha=20^\circ, 30^\circ, 90^\circ$.

XBL 8401-6741

Peak Erosion

10 μm

Steady State Erosion

10 μm

1018 Steel
30 m/s
250-300 μm SiC
 $\alpha = 20^\circ$
25°C

XBB 838-7182

Fig. 15. Surface of eroded 1018 steel at peak and steady state erosion.

Fig. 16. Incremental erosion rate curves for
1018 steel at $V=15, 30, 45$ m/s.

XBL 8401-6742

Fig. 17. Incremental erosion rate curves for 304SS eroded by 100, 250, 600 μm dia. SiC.

XBL 8401-6739

Fig. 18. Incremental erosion rate curves for 304SS eroded by 50, 100, 140 μm dia. Al_2O_3 .

XBL 843-10156

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