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Alan V. Levy and Pauline Chik

July 1982

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ON THE EROSION OF STEEL**

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ABSTRACT

The effects of erodent composition, hardness/strength, and shape on the erosion of 1020 carbon steel were determined. Tests were performed at a velocity of 80mps at two angles of impingement, $\alpha=30^\circ$ and 90° . Angular shaped particles of five compositions were used with Vickers hardness numbers (VHN) from 115 to 3000 kg/mm². It was determined that the erosion rate increased with increasing particle hardness to a constant rate for particles with a VHN greater than 700 kg/mm². The hardness was a measure of the friability of the particle composition. When the particles were strong enough to not break up upon impacting the 1020 steel surface, the erosion rate became constant. It was also determined by using angular and spherical steel erodents that angular particles can result in four times greater erosion than spherical particles.

INTRODUCTION

The erosion of ductile metals by solid particles occurs in many service environments. The impacting particles range from weak, friable materials that fragment upon striking the target metal surface to strong particles which maintain their integrity upon impacting a target metal surface. In many applications, the impacting particles are mixtures of both types of materials. Coal char, which is an erodent in coal gasifiers, is composed of many types of oxygen containing minerals as

well as carbon containing materials (1). They vary greatly in composition, strength, size, angularity and density (Fig.1).

In order to better understand the nature of the erosivity of coal char, a series of experiments was carried out using particles that represented many of the constituents of the char. Six particle compositions were separately used to erode 1020 plain carbon steel and the resulting erosion rates were compared. The possible reasons for the erosion rates measured were assessed and a mechanism of erosion as a function of particle integrity was postulated. In addition the effect of particle shape on erosivity was investigated using angular steel grit and spherical steel shot.

The knowledge of the effect of particles' composition and shape developed in this investigation is useful in establishing the test materials to use in erosion studies. The literature is full of erosion data on ductile metals obtained using a number of different erodents: SiO_2 (2), Al_2O_3 (3), SiC (4), steel shot and grit (5), and mixed groups of particles obtained from components operating in eroding environments (1, 6). The understanding of the erosivity of the various erodents presented herein is helpful in comparing data of various investigators in the literature.

TEST DESCRIPTION

1020 steel, cold rolled, was eroded at 25°C with six different compositions of particles at a velocity of 80mps. The impingement angles were $\alpha = 30^\circ$ and 90° . The 30° angle was selected as it is near the angle at which maximum erosion occurs. The 90° angle was used as it is the angle where a significantly lower erosion rate occurs on ductile metals. The composition of the particles and their hardness and density are given in Table I. Hardness was used as a means of rating the overall strength and integrity of the erodents.

TABLE I

ERODENT PARTICLES AND RATES OF EROSION OF 1020 STEEL

PARTICLE COMPOSITION	DENSITY g/cc	MOHS HARDNESS NUMBER	VICKERS* HARDNESS NUMBER kg/mm ²	EROSION RATE At $\alpha = 30^\circ$ -4 g/g X10	EROSION RATE At $\alpha = 90^\circ$ -4 g/g X10
CaCO ₃ (Calcite)		3	115	0.03	not measurable
Ca ₅ (PO ₄) ₃ (Apatite)		5	300	0.5	0.3
SiO ₂ (Sand)	2.7	7	700	3.0	1.6
Al ₂ O ₃ (Alumina)	4.0	9	1900	2.6	1.4
SiC (Silicon Carbide)	3.2	>9	3000	3.3	1.9
Steel Grit	7.9			5.3	
Steel Shot	7.9			1.4	

* 1020 Steel Hardness = 150 Kg/mm²

The tests were carried out in the room temperature erosion tester (Fig. 2). Particles were put into a vibrating hopper from which they were aspirated through a nozzle with an inside diameter of 4 mm. The particles were carried through the nozzle in an air stream: their velocity was established by the pressure drop across the nozzle and measured using the rotating disc method. The target 1020 steel specimens were placed in the erosion chamber directly below the nozzle and 1.25cm. from its exit. The impingement angles of the particles on the specimens were adjusted by rotating the specimen holder which was attached to the door of the test chamber.

The particles of the five different compositions were all angular in shape and were in the size range 180 - 250 μm . Also, two different shapes of the same particle composition were used to study the effect of shape on erosion rate. The particles used were steel shot (spherical) and steel grit (angular) with an average size of 100 μm .

Particles before and after impact and the eroded materials were observed under the scanning electron microscope.

RESULTS

The steady state erosion rate of the 1020 steel, $\text{VHN}=150 \text{ Kg/mm}^2$, eroded by each type of particle is listed in Table I. The rates for the 5 brittle type erodents are plotted in Fig. 3. It can be seen that the erosion rates are very low for the softest materials, calcite and apatite. Once a particle hardness of approximately $\text{VHN}=700$ is reached, the erosion rates are essentially the same as the hardness of the particles increases further. Thus, silica at $\text{VHN}=700$ has nearly the same erosivity as SiC at $\text{VHN}=3000$, over four times the hardness of the sand. The relatively small erosivity differences between SiO_2 , Al_2O_3 and SiC are thought to be primarily due to small differences in the angularity of the particles, the SiC having the sharpest angles in the as-crushed powder.

Fig. 4 shows the eroded surfaces of the steel caused by SiO_2 , Al_2O_3 and SiC . The production of shallow craters and platelets is very similar for all three erodents. The shape of the craters caused by the Al_2O_3 is a little less severe than those caused by the SiC , which is thought to account for the slightly lower erosion rate caused by the alumina. Figs. 5 and 6 show typical Al_2O_3 and SiC particles before and after impacting on the steel targets. The alumina has a somewhat more rounded shape than the SiC .

The size and shape of the erodents in Figs. 5 and 6 are approximately the same after impact as they were before. The strength or integrity of the particles appears to be sufficient that impacting on the 1020 carbon steel surface at a velocity of 80mps does not fracture them. The multi-fluted type facets that appear on the particles, especially visible on the SiC particles in Fig. 6, are thought to be the source of the striations seen in the shallow craters of eroded surfaces (Fig. 4). The striations are imprints of the contour facets of the particles made as they translate along the crater surface.

Fig. 7 shows the eroded surfaces of the 1020 steel impacted by the calcite and apatite particles. A significant amount of calcite and apatite are smeared on or embedded in the steel. The production of platelets and shallow craters is not as readily defined as in Fig. 4, although the platelet formation mechanism appears to be the active mechanism on both surfaces shown. The breaking up of the weak particles and their adherence to the eroded surface both decreases the kinetic energy of incoming particle segments and covers over the eroding surface with a protective layer of particle fragments. The calcite particles before and after impact are shown in Fig. 8. The marked difference in size is easily seen. The basic shape of the impacted particles appears to be similar to the particles before impact.

In order to determine how the shape of the particles affects their erosivity, steel particles in both angular and spherical shapes were used to erode the 1020 steel. An impingement angle of $\alpha=30^\circ$ at 25°C was used. Fig. 9 shows the particles after impacting on the target surface. No fracturing of the steel particles was observed; so their integrity was in the range of the SiO_2 , Al_2O_3 , and SiC particles.

Fig. 10 shows the eroded surfaces of the 1020 steel by the steel grit, left photo and the steel shot, right photo. The erosion rate, E_r , caused by the steel grit was four times greater than that caused by the steel shot, $5.3 \times 10^{-4} \text{ g/g}$ compared to $1.4 \times 10^{-4} \text{ g/g}$. The appearance of the eroded surfaces indicates the reason for the difference. The angular steel grit caused much sharper craters to form which results in a more efficient production of extruded platelets (7). The spherical steel shot developed more shallow rounded craters that did not produce platelets as efficiently.

Incremental erosion rate curves resulting from erosion at $\alpha=90^\circ$ by the weak, apatite particles and the strong, Al_2O_3 and SiC particles gives further insight into the mechanism of erosion. Fig. 11 is the erosion rate curve obtained using the apatite particles which broke up upon impacting the 1020 steel. It took almost 200 grams of particles to reach steady state erosion. The steady state erosion rate of the steel due to the apatite particles was slightly less than $0.3 \times 10^{-4} \text{ g/g}$.

Fig. 12 is the erosion rate curve obtained using the Al_2O_3 particles which did not break up on impact. The effectively much larger Al_2O_3 particle than the fragmented apatite particle transmitted sufficient force to the target metal to develop the steady state erosion "anvil" (7) with only 50gm. of particles having impacted the surface. Steady state erosion was considerably higher from the Al_2O_3 particles at $1.4 \times 10^{-4} \text{ g/g}$ of the target steel.

Fig. 13 shows the erosion rate curve obtained when SiC was used as the erodent and the impingement angle was $\alpha=90^\circ$ used for the previous two curves. It can be seen that while the erosion rate was higher, the number of particles that it took to reach steady state erosion was the same as for the Al_2O_3 particles in Fig. 12, 50gm.

DISCUSSION

The principal fact that has resulted from this investigation is that the erosivity of impacting particles is primarily a function of the concentration of force that the particle can cause in a local area of the target metal. When particles are so weak and friable that they cannot maintain their integrity when they strike the metal surface (calcite and apatite in this study) they shatter into many smaller pieces. These pieces do not have the mass necessary to provide the localized force that can form platelets efficiently and subsequently remove them by exceeding the local fracture stress of the metal.

When particles reach a level of strength and integrity for the velocity regime used in these tests where they do not fracture upon impact and the erosion rate for particles in the same density range becomes approximately the same. Thus SiO_2 , Al_2O_3 , and SiC, which are in the same density range, have about the same erosivity. Steel grit, (see Table I) is considerably more erosive. Thus, the kinetic energy of the particles when they strike the surface plays an important role in determining the amount of force that is available to make and deform platelets and to cause sub-surface work hardening.(7)

Local concentration of force is also a function of the geometry of particles. Angular particles can concentrate this force more effectively than rounded particles. This effect can be quite subtle. For a given target material with a fixed level of ductility, the small difference in angularity between alumina and silicon carbide particles can be detected by the resulting erosion rates, see Table I and Figs. 5 and 6. The

gross difference in shape between the steel grit and the steel shot causes a resulting greater difference in erosivity.

The platelet mechanism of erosion is affected by the integrity of the impacting particles and the resultant force that they can concentrate in a local area of the target material. In addition to the higher erosion rates caused by the particles that did not shatter upon impact, the amount of these particles required to reach steady state erosion was considerably less, 50gm compared to almost 200gm for the particles that did shatter. Their larger mass and attendant larger kinetic energy could concentrate more force in the eroding metal and, hence, develop a steady state number of platelets and the required sub-surface cold worked zone sooner. This effect may also relate to the size effect in erosion that has been reported extensively in the literature.(8)

The lower erosion rate caused by the particles that shattered upon impact is also partially the effect of the weight of the erodent that remains on the surface of the specimens and the possible protective blanket that they develop. However, it is thought that this effect is minor compared to the differences in localized force that are caused by strong and weak particle compositions.

CONCLUSIONS

1. The principal factor in establishing the erosivity of particles is their ability to locally concentrate force in the target metal by their mass and/or their shape.
2. Above a particle hardness of approximately 700 VHN, which is a measure of the integrity of the erodent, mild steel erodes at approximately the same rate regardless of the hardness/strength of the particle composition.
3. Angular particles are more erosive than rounded or spherical particles.

4. The platelet mechanism of erosion was the dominant material loss mechanism regardless of the erosivity of the particle compositions.
5. High integrity particles cause steady state erosion to be reached after fewer particle impacts than low integrity particles that shatter upon impact.
6. Particle compositions above a threshold level of integrity that have the same shape as eroding particles in a service environment can be used in erosion tests interchangeably.

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MAG. 200X

DESCRIPTION:
PARTICLE: ILL. NO. 6 COAL CHAR
SIZE: <10 μ UP TO OVER 100 μ

MAG. 1000X

MAG. 1000X

XBB 8210-8721

Fig. 1 Coal Char particles

Fig. 2 Room temperature erosion tester

XBB763-2073A

Fig. 3 Erosion rate of 1020 steel
by five erodents

XBL 825-697

1020 STEEL ERODED BY SiO_2
 $V = 80 \text{ m/sec}$
 $\alpha = 30^\circ$
 $E_R = 3.0 \times 10^{-4} \frac{\text{g}}{\text{g}}$

1020 STEEL ERODED BY Al_2O_3
 $V = 80 \text{ m/sec}$
 $\alpha = 30^\circ$
 $E_R = 2.6 \times 10^{-4} \frac{\text{g}}{\text{g}}$

1020 STEEL ERODED BY SiC
 $V = 80 \text{ m/sec}$
 $\alpha = 30^\circ$
 $E_R = 3.3 \times 10^{-4} \frac{\text{g}}{\text{g}}$

Fig. 4 Eroded surfaces of 1020 steel eroded
 by SiO_2 , Al_2O_3 , SiC

XBB8110-9335

XBB 810-9332

Fig. 5 Al_2O_3 erodent particles before and after impact.

SIC BEFORE IMPACT
35 μm

SIC AFTER IMPACTED
ON 1020 STEEL
 $V = 80 \text{ m/sec}$
 $\alpha = 30^\circ$
35 μm

SIC AFTER IMPACTED
ON 1020 STEEL
 $V = 80 \text{ m/sec}$
 $\alpha = 90^\circ$
35 μm

Fig. 6 SiC erodent particles before and after impact

XBB8110-9333

1020 STEEL ERODED BY CaCO_3
 $V = 80 \text{ m/sec}$
 $\alpha = 30^\circ$

1020 STEEL ERODED BY APATITE
 $V = 80 \text{ m/sec}$
 $\alpha = 30^\circ$

XBB 810-9329

Fig. 7 Eroded surfaces of 1020 steel eroded by calcite and apatite

CaCO_3 BEFORE IMPACT
30 μm

CaCO_3 AFTER IMPACTED
ON 1020 STEEL
 $V = 80 \text{ m/sec}$
 $\alpha = 30^\circ$
30 μm

XBB 810-9330

Fig. 8 Calcite erodent particles before and after impact

35 μ m

STEEL GRIT AFTER IMPACTED
ON 1020 STEEL

$V = 80 \text{ m/sec}$

$\alpha = 30^\circ$

35 μ m

STEEL SHOT AFTER IMPACTED
ON 1020 STEEL

$V = 80 \text{ m/sec}$

$\alpha = 30^\circ$

Fig. 9 Steel particles, angular and
spherical after impact

XBB8110-9331

10 μm

1020 STEEL ERODED BY STEEL GRIT

$$V = 80 \text{ m/sec}$$

$$\alpha = 30^\circ$$

$$E_R = 5.3 \times 10^{-4} \frac{\text{g}}{\text{g}}$$

10 μm

1020 STEEL ERODED BY STEEL SHOT

$$V = 80 \text{ m/sec}$$

$$\alpha = 30^\circ$$

$$E_R = 1.4 \times 10^{-4} \frac{\text{g}}{\text{g}}$$

XBB 810-9334

Fig. 10 Eroded surfaces of 1020 steel eroded by angular and spherical steel particles

Fig. 11 Incremental erosion rate curve
for 1020 steel by apatite

XBL 825-694

Fig. 12 Incremental erosion rate curve
for 1020 steel by Al_2O_3 particles

XBL 825-696

Fig. 13 Incremental erosion rate curve
for 1020 steel by SiC particles

XBL 825-695

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