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EFFECT OF MECHANICAL SURFACE AND HEAT TREATMENTS ON EROSION RESISTANCE

Joshua Salik and Donald H. Buckley
Lewis Research Center
Cleveland, Ohio

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EFFECT OF MECHANICAL SURFACE AND HEAT TREATMENTS ON EROSION RESISTANCE

by Joshua Salik* and Donald H. Buckley

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

ABSTRACT

The effects of mechanical surface treatments as well as heat treatments on the erosion resistance of 6061 aluminum alloy and 1045 steel were studied. Mechanical surface treatments were found to have little or no effect on the erosion resistance. This is due to the formation by particle impact of a work-hardened surface layer regardless of the initial surface condition. It was found that the erosion resistance of Al single crystals is independent of orientation. This is due to destruction of the surface microstructure and formation of a polycrystalline surface layer by the impact of erodant particles as observed by X-ray diffraction. While upon solution treatment of annealed 6061 aluminum the increase in hardness is accompanied by an increase in erosion resistance, precipitation treatment which causes a further increase in hardness results in slightly lower erosion resistance. Using two types of erodant particles, glass beads and crushed glass, it was found that the erosion rate is strongly dependent on erodant particle shape, being an order of magnitude higher for erosion with crushed glass as compared to glass beads. Moreover, while for erosion with glass beads heat treatment of 1045 steel had a profound effect on its erosion resistance, little or no such effect was observed for erosion with crushed glass. It is thus concluded that different mechanisms of material removal are involved in these two cases.

INTRODUCTION

The erosion of materials by streams of solid particles has recently gained increased interest due to its severe role in the failure of components in aircraft (ref. 1) and in coal gasification processes (refs. 2,3). For an excellent review see reference 4. Most of the recent work, however, concentrated on the mechanisms involved in the erosion process, and little fundamental work was done dealing with the effect of properties of materials on their erosion resistance. The most extensive comparative studies of the erosion resistance of various materials were recorded by Finnie, et al. (ref. 5) and more recently by Hansen (ref. 6) and by Jones and Lewis (ref. 7). The effects of mechanical and heat treatments on the erosion resistance, however, have not as yet been thoroughly investigated.

In the work reported here the effects of some mechanical surface treatments as well as heat treatments on the erosion resistance of two common structural alloys - 6061 aluminum and 1045 steel - were studied. This study is a part of a general program aimed at gaining a better understanding of the effects of various material properties on erosion behavior in order to find possible means of reducing erosive wear.

MATERIALS

Samples of 6061 aluminum (1.0% Mg; 0.6% Si; 0.25% Cu; 0.25% Cr) were prepared from the same stock. They were annealed for 3 hours at 420° C before running any tests. Solution treatment was done at 530° C for 6 hours, and precipitation treatment was done at 178° C for different times as listed in table I.

The 1045 steel samples (0.43-0.50% C; 0.6-0.3% Mn; maximum 0.04% P; maximum 0.05% Si) were also prepared from the same stock. Separate specimens were subjected to the following heat treatments (see table II).

(1) Annealing performed by heating to 740° C, furnace cooling to 650° C and cooling to room temperature in still air;
(2) Spheroidizing by first annealing and then holding at 705° C for 24 hours;
(3) Normalizing performed by heating to 900° C and cooling in still air;
(4) Quenching performed in water after austenitizing at 855° C;
(5) Tempering performed on quenched samples by keeping for 1 hour at 120°, 315°, 540°, or 685° C;
(6) Austempering performed by first austenitizing at 855° C and quenching in a salt bath kept at either 400° or 510° C.

EXPERIMENTAL PROCEDURE

Specimens were eroded in an industrial sand-blasting apparatus. Two types of erodant particles were used - glass beads with an average diameter of 15 μm and crushed glass. Figure 1 shows micrographs of the two types of erodant particles.

Argon was used as the driving gas in order to minimize corrosion effects. The nozzle diameter was 1.18 mm. The distance between nozzle and specimen was 13 mm. The erosion tests were made at normal incidence. Although the values of some experimental parameters such as flow rate and speed of particles were not measured, reproducible measurements of wieght loss were obtained with a variation not exceeding ±3 percent.

A Vickers microhardness tester was used for the study of the effect of mechanical surface treatments. Since the heat treatments resulted in rough surfaces which did not enable microhardness tests to be made, the Rockwell test was used in this case after polishing the samples.

RESULTS AND DISCUSSION

The effect of mechanical surface treatments was studied first. Several samples of 6061 aluminum alloy were subjected to the treatments listed in table III, after which their surface roughness and microhardness were measured. They were then eroded using glass beads for 10 minutes under the conditions described in the previous section. The results are also listed in table III. It is clear from these results that the erosion resistance is insensitive to the mechanical surface treatments listed. This is probably due to the fact that any effect that the surface condition may have on the erosion resistance is limited to the very first stages of erosion and, after the few outermost layers have been

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*NRC-NASA Research Associate.

eroded away, all the samples regardless of their initial surface condition have identical surface structure, namely the one resulting from the impact of the eroding particles. Thus, surface modifications caused by the particle impact force of the glass beads must exceed or mask any other effect of mechanical surface treatment.

The nature of the surface resulting from particle impact was investigated in a previous study (ref. 8) where the formation of a work-hardened surface layer as a result of impact by a single layer particle was observed. The same observation was made in the present study for the surface resulting from erosion by a continuous stream of small particles. Cross-sectioning of the eroded specimen followed by etching revealed the existence of a work-hardened layer, which is shown in figure 2. It is with this work-hardened layer that the erodant particles interact, and thus the erosion resistance is determined by the properties of this layer.

This was also demonstrated by the erosion behavior of Al single crystals. Three Al single-crystal samples with three different orientations, namely (100), (110), and (111), were prepared from the same stock and then erosion tested for 2 minutes using glass beads. It might have been expected that the different atomic planes, which have different atomic densities and cohesive forces, would give rise to different erosion resistances. However, the results, presented in table IV, clearly show that the erosion rate is the same, within experimental error, for all three orientations. This, again, is probably due to the formation of a deformed, recrystallized surface layer with which the erodant particles interact and which is identical for all three crystal orientations. The existence of this layer is demonstrated by the X-ray back-reflection photographs obtained from the (110) sample before and after erosion, which are shown in figure 3. It is seen that the impact of the eroding particles resulted in destruction of the surface microstructure and transformation to a polycrystalline surface as a result of recrystallization. The energy of the impacting particles is sufficient to bring about the recrystallization. Thus, all crystal surfaces become essentially polycrystalline and give, therefore, the same erosion resistance.

Next, the effect of heat treatment on the erosion resistance of the 6061 aluminum alloy was studied. The samples were subjected to the heat treatments listed in table I, where the Rockwell E hardness values are also given. Erosion tests which lasted 10 minutes each using glass beads as the erodant particles were then conducted. The results are also summarized in table I. The main observation emerging from these results is that while solution treatment, which results in increased hardness, also brings about a higher erosion resistance, the precipitation treatment, which causes a further increase in hardness for a short time and then reduced the hardness due to an averaging and agglomeration of precipitation, results in poorer erosion resistance. This behavior is somewhat different from that observed by Finnie, et al. (ref. 5) for pure metals, where the erosion resistance, defined as the reciprocal of weight loss during an erosion test, was found to be linearly proportional to hardness. Thus, as pointed out by others (ref. 1) hardness cannot be generally used as a measure of the erosion resistance, especially for aluminum alloys.

The effect of heat treatment on the erosion resistance of 1045 steel was studied next. Several samples of 1045 steel were subjected to the heat treatments listed in table II, which also lists the Rockwell A hardness values resulting from the various heat treatments. Erosion tests on these samples were done with the two types of erodant particles - glass beads and crushed glass - and lasted 10 and 5 minutes, respectively. The results are summarized in table II and are also presented graphically in figure 4. It is clear from that figure that, as in the case of the 6061 alloy, there is no correlation between the erosion resistance and the hardness.

The most conspicuous feature of the results is revealed by comparing the results for the two types of erodant particles. First, an order of magnitude higher weight loss occurs upon erosion with crushed glass as compared with that obtained for erosion with glass beads. Second, and probably more significant, while for erosion with glass beads the heat treatment and the resulting microstructure have a very strong effect on the erosion resistance, little or no such effect is observed for erosion with crushed glass. This indicates that different mechanisms of material removal are involved in these two cases. SEM examination of the surface of annealed 1045 steel which was eroded by these two types of erodant particles also shows the different surface morphologies. The SEM micrographs presented in figure 5 clearly show that for erosion with crushed glass the dominant mechanism of material removal is cutting, whereas for erosion with glass beads it is deformation-induced fracture of surface layers.

SUMMARY OF RESULTS AND CONCLUSIONS

From the erosion experiments conducted in this study with 6061 aluminum alloy and 1045 steel the following major results and conclusions were obtained.

1. Mechanical surface treatments were found to have little or no effect on erosion resistance.
2. The energy of impacting erodant particles was sufficient to recrystallize the surface layers of aluminum single crystals.
3. Metallurgical structural changes may be more significant to erosion resistance than increases in hardness.
4. The erosion rate is strongly dependent upon particle shape. In this study erosion with crushed glass was an order of magnitude higher than that observed with glass beads.

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TABLE I. - HARDNESS AND EROSION OF 6061 ALLOY

SUBJECTED TO VARIOUS HEAT TREATMENTS

Heat treatment	Hardness (Rockwell E)	Weight loss on a 10-min erosion test, g
Annealed	14	0.0422
Solution treated	67	.0326
Aged for 15 minutes	77	.0329
Aged for 30 minutes	83	.0331
Aged for 1 hour	81	.0348
Aged for 2 hours	77	.0361
Aged for 4 hours	73	.0370
Aged for 7 hours	68	.0364

TABLE II. - MICROSTRUCTURE, HARDNESS, AND EROSION OF 1045 STEEL SUBJECTED TO

VARIOUS HEAT TREATMENTS

Heat treatment	Phases present	Hardness (Rockwell A)	Weight loss on erosion for 5 min with crushed glass, g	Weight loss on erosion for 10 min with glass beads, g
Annealed	Ferrite + coarse pearlite	51	0.121	0.0242
Spheroidized	Cementite in ferrite matrix	47	0.119	0.0296
Normalized	Ferrite + fine pearlite	57	0.121	0.0206
Water quenched	Martensite in retained austinite matrix	68	0.117	0.004
Water quenched and tempered at 120° C	Transition carbide in austenite matrix	68	0.115	0.0041
Water quenched and tempered at 315° C	Tempered and untempered martensite	67	0.120	0.0179
Water quenched and tempered at 540° C	Cementite in ferrite matrix	65	0.120	0.0200
Water quenched and tempered at 685° C	Cementite in ferrite matrix	60	0.116	0.0248
Austenitized and austempered at 400° C	Lower bainite	61	0.113	0.0197
Austenitized and austempered at 510° C	Upper bainite	58	0.119	0.0139

TABLE III. - SURFACE PROPERTIES AND EROSION OF 6061 ALLOY

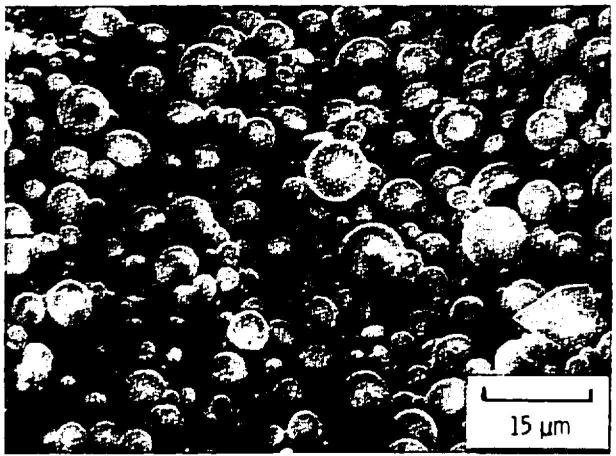
SUBJECTED TO VARIOUS MECHANICAL TREATMENTS

Surface treatment	Surface roughness, μm,	Microhardness, kg/mm^2	Weight loss on a 10-min erosion test, g
Annealed (baseline)	Variable	41	0.0410
Cold rolled	0.76	48	.0418
Ground	.37	50	.0405
Sand blasted	3.68	74	.0417
Glass bead blasted	2.29	76	.0412
Alundum blasted	4.06	110	.0414
Shot peened	Out of range	131	.0419

TABLE IV. - EROSION OF AL SINGLE CRYSTALS

Orientation	Weight loss on a 2-min erosion test, g
(100)	0.0120
(110)	.0115
(111)	.0118

(a) CRUSHED GLASS.



(b) GLASS BEADS.

Figure 1. - Erodant particles used in this study.

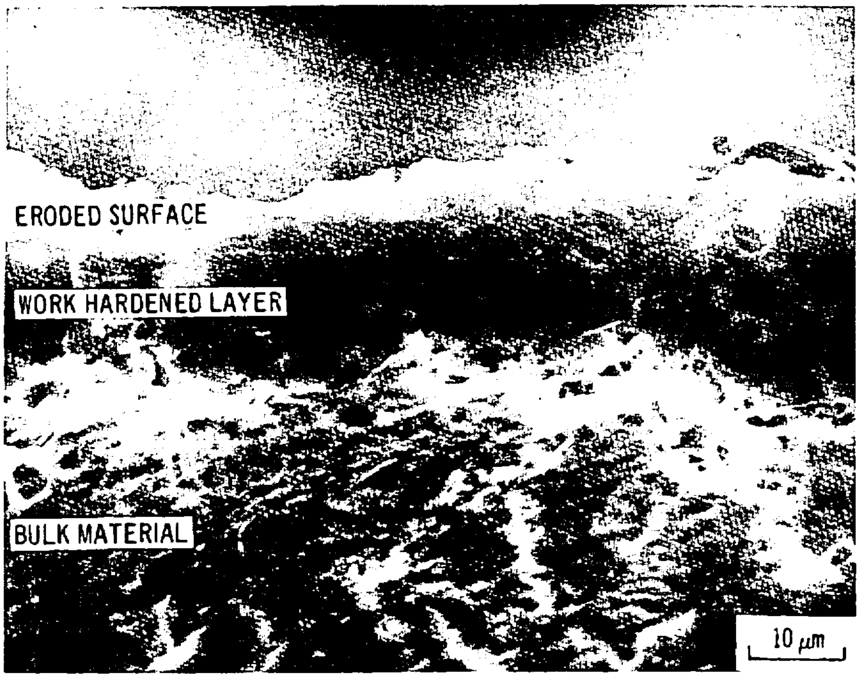
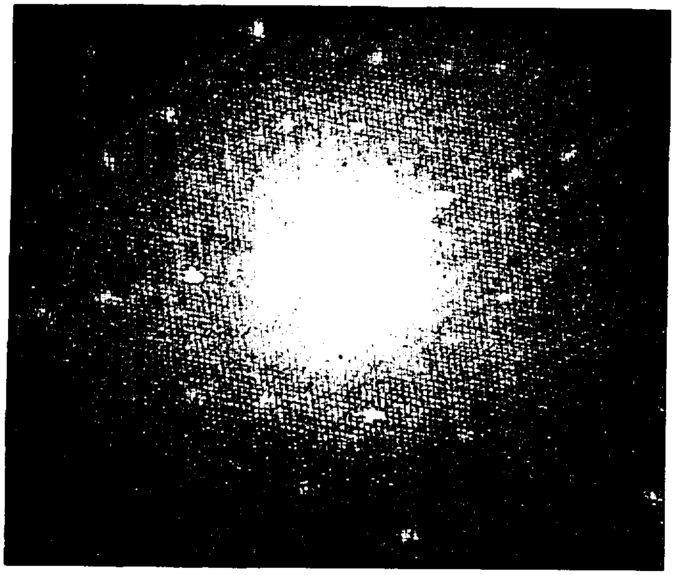
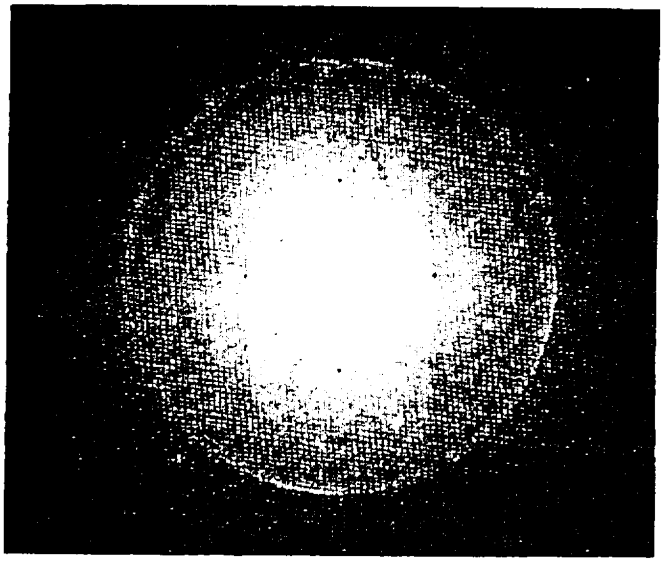


Figure 2. - Cross section at bottom of crater formed by erosion of annealed 6061 aluminum alloy. Etched with a 5% HF (48%), 10% H_2SO_4 (conc.), and 85% H_2O solution.



(a) BEFORE EROSION.



(b) AFTER EROSION.

Figure 3. - X-ray diffraction pattern obtained from Al (110) single crystal.

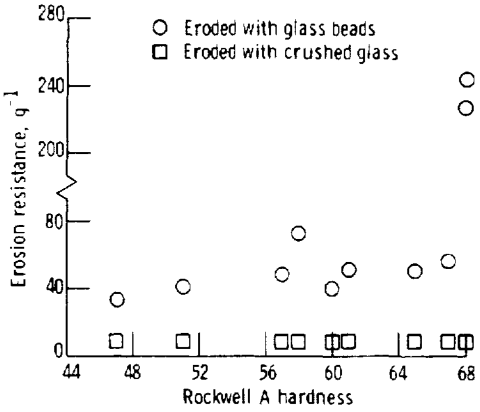
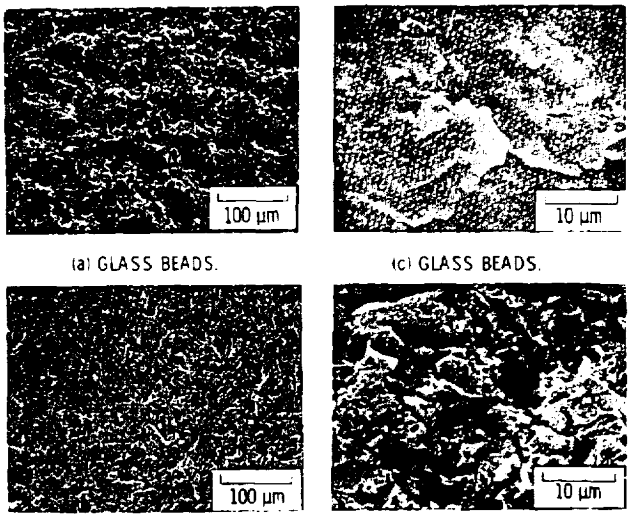


Figure 4. - Erosion resistance versus hardness for 1045 steel after various heat treatments.



(a) GLASS BEADS.

(c) GLASS BEADS.

(b) CRUSHED GLASS.

(d) CRUSHED GLASS (BOTTOM OF CRATER.

Figure 5. - SEM micrographs of the surface of annealed 1045 steel after erosion with glass beads and crushed glass.

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15. Supplementary Notes

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16. Abstract

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