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ADHESIVE MATERIAL TRANSFER IN THE EROSION OF AN ALUMINUM ALLOY

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16 Abstract

In order to study the basic mechanisms of erosion, hardened steel balls were shot into annealed 6061 Al alloy targets at velocities of up to 150 m/sec. The projectiles were collected and examined by a scanning electron microscope combined with energy-dispersive X-ray analyzer and it was found that target material in substantial amounts is adhesively transferred to the projectile The transferred material forms on the projectile surface a layer the thickness of which increases with increases in impact velocity

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SUMMARY

A clear discrepancy exists between erosion theories which predict negligible erosion of ductile materials at normal incidence and the experimental observation of substantial erosion under these conditions. In order to account for this discrepancy the possible role of adhesive material transfer as an erosion mechanism was studied.

Hardened steel balls were shot into annealed 6061 aluminum (Al) alloy targets at velocities of up to 150 m/sec. The projectiles were collected and examined by a scanning electron microscope combined with energy-dispersive X-ray analyzer and it was found that target material in significant amounts is adhesively transferred to the projectile. The transferred material forms on the projectile surface a continuous layer covering essentially all the area which had been in contact with the target. The thickness of this layer increases with increasing impact velocity.

It is thus established that adhesive material transfer plays a substantial role in erosion and should be taken into account in theoretical treatments of erosion.

INTRODUCTION

The erosion of solids by streams of solid particles has gained a growing interest in recent years due to the severe role it plays in aircraft (ref. 1) and in coal gasification processes (ref. 2). Several theoretical (refs. 3 to 5) as well as numerous experimental (refs. 6 to 14) studies of the mechanisms involved were conducted. Two mechanisms were considered for the erosion of ductile materials: a cutting wear mechanism associated with forces parallel to the surface under attack (ref. 3) and a so-called deformation wear associated with forces normal to the surface (ref. 6).

However, whereas good agreement between theory and experiment has been obtained for erosion at oblique incidence there is a clear discrepancy between the theoretical prediction according to which practically no erosion should occur at normal incidence and the experimental results which exhibit substantial erosion (c.a., 50% of the maximum erosion rate obtained at $\sim 17^{\circ}$ incidence for Al eroded by Al_2O_3 particles). It seems quite possible, therefore, that some mechanisms which are actually involved in erosion have been overlooked.

Adhesive material transfer between the incident particle and the surface being eroded is a likely mechanism candidate since many of the conditions that occur in sliding mechanical contact (i.e., frictional sliding) also exist in erosion contacts, namely intimate interfacial contact between the impacting particle and the substrate due to rupturing of surface films and flowing of material from the impact region. The analogy to this in sliding contacts is junction growth and Bowden and Tabor (ref. 15) showed significant adhesion following junction growth during sliding.

In order to ascertain the role, if any, of adhesive material transfer in erosion, single particle impingement experiments at normal incidence were performed. The projectiles were later collected and examined by scanning electron microscope combined with energy-dispersive X-ray analyzer in order to observe any evidence of adhesive material transfer.

APPARATUS AND PROCEDURE

The samples used for this study were 37×25×6 millimeter pieces of Al 6061 alloy which had been annealed at 420° C for 3 hours. The projectiles were AISI 52100 bearing steel balls of 3.2 millimeter diameter.

The gun used for shooting the projectiles was of the same design as the one used by Hutchings and Winter (ref. 16) with a barrel length of 20.5 centimeters using nitrogen as the driving gas and hollow teflon sabots (c.a. 2.7 gram by weight) for holding the projectile. However, unlike those workers who measured the sabot velocity assuming it is identical with the projectile velocity, a direct measurement of projectile velocity was made here since there were some indications that the projectile velocity is in some cases lower than the sabot velocity due probably to frictional and other forces between the sabot and projectile. Two solar cells illuminated by 6.3 volts d.c. bulbs and placed 5 centimeters apart were used for measuring the velocities. A schematic of the apparatus is shown in figure 1.

The gun was operated at pressure up to 4.1 MPa with aluminum rupture diaphragms from 0.06 to 0.25 millimeter thickness. Particle velocities ranged from 85 to 180 meters per second.

RESULTS AND DISCUSSION

Figure 2 presents the X-ray emission spectrum obtained from a ball which had not been shot at the target. The peaks at 6.4 keV and 7.1 keV are, respectively, the K_α and $K_{\beta 1}$ emission lines of Fe. The peak at 1.7 keV is the SiK_α emission line.

Figure 3 is the X-ray emission spectrum obtained from a ball that had been shot at the Al target at a speed of 107 m/sec. A peak of 1.5 keV due to AlK_α emission is clearly observed, indicating transfer of Al from the target to the projectile. However, the amount of material transferred in this case was too small to be observed in the SEM and it was necessary to go to higher impact velocities in order to gain information about the morphology of the transferred material.

Figure 4(a) is an SEM micrograph of a ball which had been shot at the target at a speed of 147 m/sec. It shows that the target material is transferred to the projectile in a form of a continuous layer. The overall surface morphology of the ball after impact is schematically illustrated in figure 5 where two regions are shown. The upper one which is the one that had been in direct contact with the target during impact and is covered with a layer of transferred material whereas the lower one is that which had not been in contact with the target and it is essentially "clean." The covered part also contains occasional chunks of target material. An example of such a chunk is shown in figure 6 together with the corresponding AlK_α emission map.

Figure 4(c) is the X-ray emission spectrum taken from the area covered by the layer of transferred material. It can be seen that this layer is thick enough to extinguish the SiK_α emission line of the ball material at 1.7 keV. Also note that the FeK_α peak at 6.4 keV obtained from the covered area is higher than the one obtained from the "clean" area which is shown in figure 4(b). This is due to the fact that the absorption coefficient of Al for FeK_α radiation which is 252.4 cm^{-1} (ref. 17) is lower than that of Fe for the same radiation which is 560.0 cm^{-1} (ref. 17). The intensity ratio in these two cases was used to estimate the thickness of the layer of transferred material and it was found to be of the order of 3 μm. Since this is a significant amount of material (of the order of 3×10^{-4} g per particle) it may be inferred that adhesive material transfer plays a substantial role in the erosion process and thus should be taken into account in any theoretical treatment of erosion.

Many other features of erosion are still unknown and it is planned to extend this work to other materials and different conditions (e.g., oblique incidence) in order to gain a better understanding of it.

CONCLUSIONS

Adhesive material transfer has been demonstrated to constitute a mechanism of erosion of ductile materials at normal incidence. Since theories based on cutting wear and deformation mechanisms of erosion were unable to explain the occurrence of erosion at normal incidence, this finding accounts, at least partially, for the difference between theoretical and experimental results.

The material transferred via this mechanism forms on the projectile surface a layer the thickness of which increases with the increase of impact velocity. At an impact velocity of 147 m/sec substantial amounts of target material can be removed by this mechanism.

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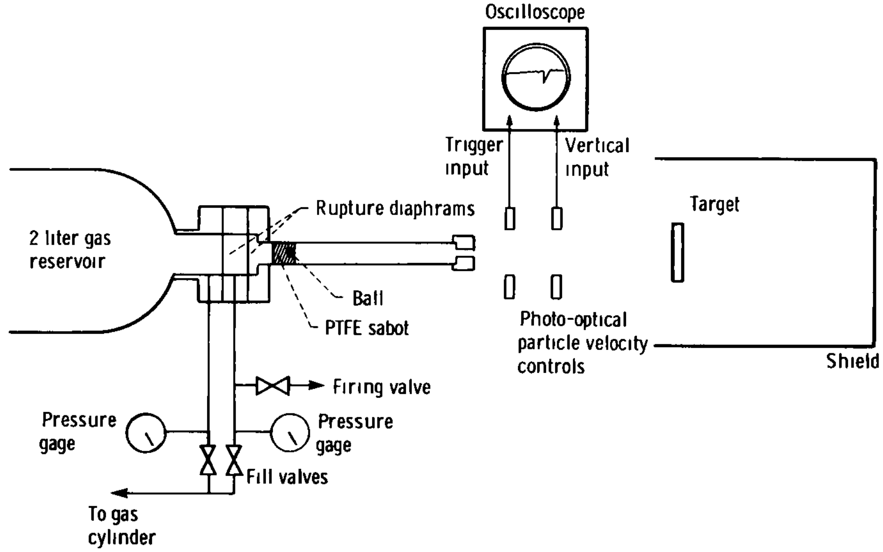


Figure 1 - Schematic of single particle impingement apparatus

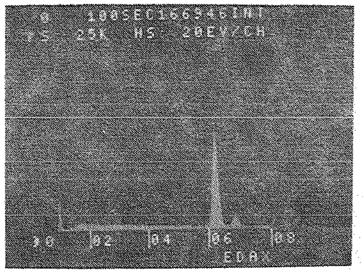


Figure 2. - X-ray emission spectrum from a virgin ball.

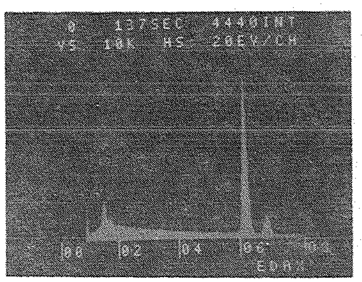
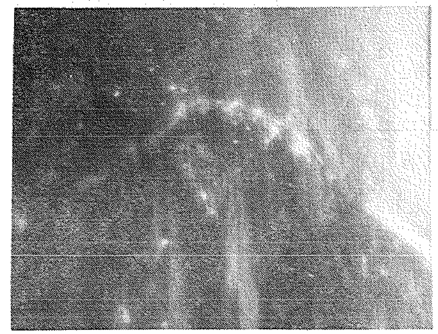
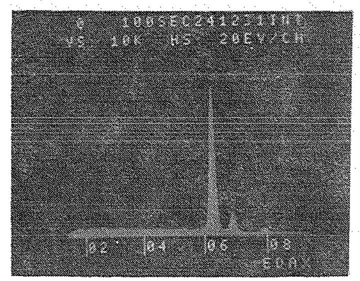


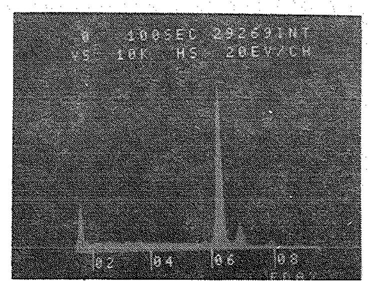
Figure 3. - X-ray emission spectrum from a ball after hitting the target at 107 m/sec. Note that the layer of transferred material is thin enough for the SiK_α peak to be observed.



(a) An SEM micrograph of a ball after hitting the target at 180 m/sec. (X65)



(b) X-ray emission spectrum from upper part of (a).



(c) X-ray emission spectrum from lower part of (a).

Figure 4.

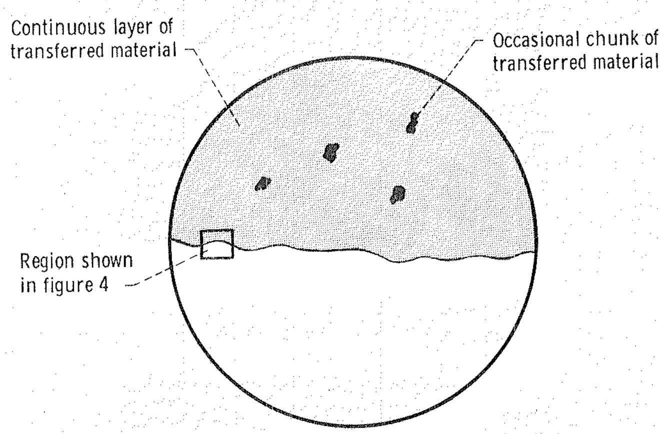
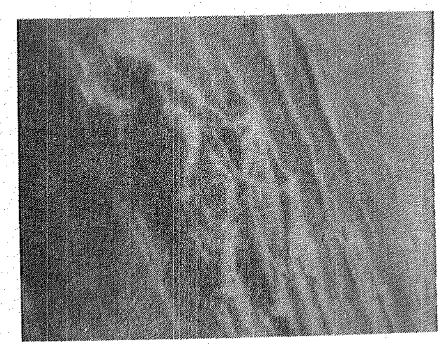
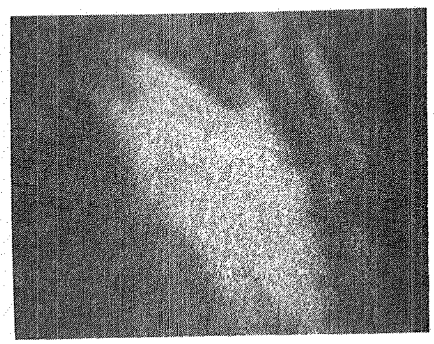


Figure 5. - Schematic illustration of steel ball surface after impinging on annealed 6061 aluminum surface at 180 μ/sec.



(a) An SEM micrograph of a chunk of transferred target material on the surface of the ball after hitting the target at 180 m/sec. (X1500)



(b) An AlK_{α} X-ray emission map of the region shown in (a).

Figure 6.

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