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By

S. K. Das and M. Kaminsky

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REDUCTION OF SURFACE EROSION CAUSED BY HELIUM BLISTERING: COMPARISON BETWEEN VACUUM-CAST AND SINTERED-BERYLLIUM†

S. K. Das and M. Kaminsky
Argonne National Laboratory, Argonne, Illinois 60439

Summary

The blister formation and the erosion associated with blistering in a vacuum cast beryllium foil and in a foil of sintered beryllium powder have been investigated for irradiation at room temperature and at 600°C with 100 keV $^4He^+$ ions for total doses of 0.5 to 1.0 C cm^{-2} For room temperature irradiation the blisters in sintered beryllium powder are smaller in size than in vacuum cast beryllium. For irradiation at 600°C large scale exfoliation of blisters was observed for vacuum cast beryllium but only small amount of exfoliation was seen for sintered beryllium powder. The results show a reduction in erosion rate in sintered beryllium as compared to the erosion rate in vacuum cast beryllium. For room temperature irradiation no erosion rate could be determined for the sintered beryllium foil since no blister exfoliation was observed. For 600°C irradiation the erosion rate for sintered beryllium foil is more than an order of magnitude smaller than for vacuum cast beryllium.

Introduction

It has been pointed out that during the operation of thermonuclear reactors the surfaces of components exposed to bombardment by energetic helium ions from the plasma region can be seriously eroded by radiation blistering.[1-4] Recently, attempts have been made[5] to reduce surface erosion due to helium blistering. One possible way to reduce surface erosion due to helium blistering in fusion reactor components is to maintain the surfaces at a high enough temperature (e.g. > 900°C for Nb and V) so that some of the implanted helium is released without forming large bubbles.[3,6,7] However, the operating temperatures of various components may be limited by other design criteria. A more desirable solution would be to choose a material with a microstructure which minimizes the formation of blisters. A promising class of materials appears to be sintered metal powder with small average grain sizes and of low atomic number Z. Initial studies of the surface erosion of sintered aluminum powder (SAP) and of aluminum due to blistering by helium ions (100 keV, dose 1.0 C cm^{-2}) reveal a high reduction in the erosion rate in SAP by more than three orders of magnitude as compared to the erosion rate of pure aluminum[5]. This paper presents results of recent studies of another low Z material, beryllium.

Verbeek and Eckstein[8] observed blister formation in beryllium irradiated at room temperature with low energy (15 keV) D^+ and He^+ ions, however, no detailed study of erosion rates or the effect of temperature were done. This paper reports the first results on the blistering behavior of two differently fabricated beryllium foils for energetic helium ion irradiation at 100 keV for two irradiation temperatures.

Experimental Procedures

Two types of beryllium were used in these experiments. One was a beryllium foil†† hot-rolled from an ingot that was vacuum-cast. The other sample was a disc cut from an ingot that was prepared by sintering beryllium powder and subsequent hot rolling*. The targets were first mechanically polished and then electropolished in an electrolyte containing 100 ml phosphoric acid, 30 ml glycerol, 30 ml ethanol, and 30 ml sulphuric acid at an applied voltage of 35 volts. The targets were irradiated with 100 keV $^4He^+$ ions from a 2-MeV Van de Graaff accelerator. During the irradiation the vacuum in the target chamber was maintained at ~ 5 x 10^{-8} Torr by ion pumping. The ion flux was 1 x 10^{14} ions cm^{-2} sec^{-1}. The targets irradiated at 600°C were heated directly by ohmic heating, and the temperature was measured with an infrared pyrometer. Other details of irradiation can be found elsewhere.[2] After irradiation the targets were examined in a Cambridge Stereoscan S4-10 scanning electron microscope. The two types of beryllium foils used in the present experiments were characterized by transmission electron microscopy for grain size and dislocation density. The average grain size was ~ 3μm in sintered beryllium and ~ 5μm in vacuum-cast beryllium.

Results and Discussion

Figure 1 (a) shows a scanning electron micrograph of vacuum-cast beryllium irradiated at room temperature with 100 keV He^+-ions to a dose of 1.0 C cm^{-2}. Blisters with diameters ranging from about 5 μm to 35 μm can be observed. In a few areas the blisters have exfoliated and a second skin has begun to rupture. Figure 1 (b) shows a micrograph of a sintered beryllium foil irradiated under the same conditions mentioned above. Blisters can be observed, but the average blister size is smaller than those seen in Figure 1 (a), and the diameters range now from about 5 μm to 15 μm. No exfoliation of blisters could be observed. The pits seen in Figure 1 (b) are not due to blister exfoliation but were present in the unirradiated samples as can be seen in Figure 1 (c).

Figures 2 (a) and (b) show micrographs at two different magnifications of a vacuum-cast beryllium foil irradiated at 600°C with 100 keV He^+-ions to a dose of 0.5 C cm^{-2}, which is half the dose used for the room temperature irradiation [see Figure 1 (a)]. Very serious blister exfoliation can be observed. In some areas as many as seven skin layers have exfoliated and have been lost [Figure 2 (b)]. In contrast the sintered beryllium foil shows greatly reduced blister exfoliation [see Figure 2 (c)]. Only in a few areas a maximum of two blister skins have been lost. The average blister size is smaller in the sintered beryllium as compared to the vacuum-cast beryllium.

From measurements of the blister skin thickness, and the area from which the skins were lost an estimate of the erosion yields has been made. Table 1 summarizes the results of such yields for the two types of beryllium foils for room temperature and 600°C irradiations. For the sake of comparison our earlier results[5] for annealed aluminum and sintered aluminum powder (SAP) are included. For both types of beryllium foils one notices an increase in the erosion rates as the temperature is increased from room temperature to

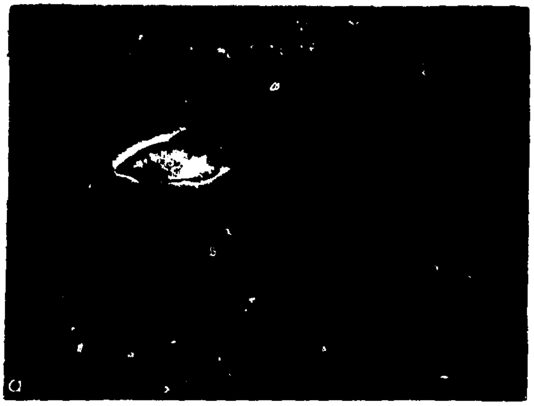

Figure 1 Scanning electron micrographs of (a) beryllium vacuum-cast from powder, and (b) sintered beryllium powder irradiated with 100 keV $^4He^+$ ions at room temperature to a dose of 1.0 C cm^{-2}, (c) an unirradiated area of sintered beryllium powder.

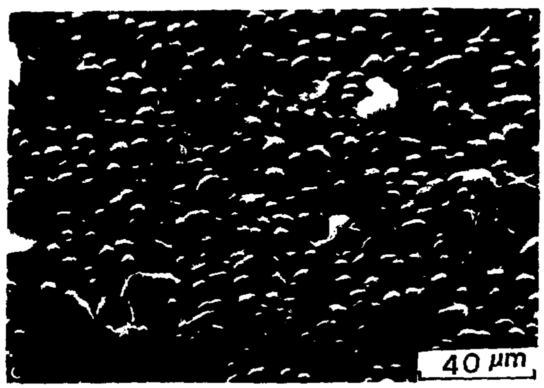

Figure 2 Scanning electron micrographs of beryllium irradiated at 600°C with 100 keV $^4He^+$ ions. (a) beryllium vacuum-cast from powder irradiated to a dose of 0.5 C cm^{-2}, (b) an enlarged view of one of the exfoliated areas in (a), (c) sintered beryllium powder irradiated to a dose of 1.0 C cm^{-2}.

Table 1: Erosion Yields for Be and Al Irradiated with 100 keV $^4He^+$ ions.

Type of Material	Erosion Yields in atoms/incident ion	
	Room Temp. (Dose 1.0 C cm^{-2})	600°C (Dose 0.5 C cm^{-2})
Vacuum-Cast Be	~ 0.001	0.3 ± 0.1
Sintered Be	Blisters, no exfoliation	0.02 ± 0.01 (dose 1.0 C cm^{-2})
		400°C (Dose 1.0 C cm^{-2})
Annealed Al	1.75 ± 0.25	0.12 ± 0.05
Sintered Aluminum Powder (SAP)	0.001	Blisters, no exfoliation

600°C. This is the same trend observed earlier[3,6,9] for such metals as V, Nb, and stainless steel. In contrast aluminum shows a decrease in the erosion rate at 400°C as compared to room temperature. We have observed earlier that the blister exfoliation and the erosion rates are at a maximum at a temperature which is high enough so that the surface can be deformed easily (reduced yield strength, and increased gas kinetic pressure in the bubble) but low enough so that helium release from the surface is still very small. For aluminum, which has a much lower melting point than metals such as beryllium, vanadium and niobium, this maximum lies at temperatures below those for vanadium for example (~ 500°C)[3].

Another striking result is that the sintered beryllium shows significantly less erosion than the vacuum-cast beryllium for both temperatures. At 600°C the erosion yield for sintered beryllium is reduced by more than one order of magnitude in comparison with the vacuum-cast beryllium. It is of interest to note that the erosion rates at room temperature for both types of beryllium are lower by more than three orders of magnitude than for annealed aluminum. At room temperature the erosion yield for sintered beryllium is even lower (nondetectable) than for sintered aluminum powder.

The drastic reduction in erosion yield in sintered aluminum powder as compared to annealed aluminum was attributed[5,10] to the dispersion of trapped helium at the large Al-Al_2O_3 interfaces at the large grain boundaries in SAP. (The average grain size in SAP was ~ 0.5 μm as compared to ~ 300 μm for annealed aluminum). The observed reduction in erosion yields in sintered beryllium in comparison to the vacuum-cast beryllium is not clearly understood at the present, since the difference in the average grain size between these two types of beryllium is not very large as mentioned earlier. In order to understand the observed differences in blistering, measurements of the depth profile of trapped helium in the two types of samples have been started. In addition, measurements of helium blistering on a non hot-rolled sintered beryllium sample are in progress.

Conclusions

For identical irradiation conditions (100 keV He^+ ions, Dose 0.5-1.0 C cm^{-2}) the erosion yields for sintered beryllium powder are reduced in comparison to those observed for vacuum-cast beryllium for the two temperatures studied. For room temperature irradiation the erosion yields for sintered beryllium are even lower than those reported earlier[5] for sintered aluminum powder. Thus, the use of sintered beryllium powder for such plasma device components as beam limiters appears promising.

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††Kawecki Berylco Industries, Inc., Hazelton, Pennsylvania.

*Brush Wellman, Cleveland, Ohio.