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TITLE DIFFUSION IN SHOCK ACTIVATED Be-Al INTERFACES

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Diffusion in Shock Activated Be-Al Interfaces

N. E. Elliott, K. P. Staudhammer and K. A. Johnson [1]

Over the past decade, a number of studies have been conducted that have shown significant shock effects on materials.[2,3,4] Shock activation has been successfully employed as an aid in hot pressing hard to consolidate powdered material, with concomitant decrease of temperature and/or time required for sintering.[5,6] Mechanisms for this beneficial effect are presently not understood in detail. However, the effect has a strong dependency on the degree of introduction of atomic level defects, such as dislocations, in the material during shock.[7] The objective of this study was to obtain initial information on a related effect, the diffusion of solid aluminum clad beryllium subjected to an explosive shock loading environment. The post shock elemental concentration profiles were evaluated as a function of time and temperature. An experimental approach allows the routine and convenient observation of effects of shock pressures from roughly 1GPa to 170GPa in a single sample. The exact pressures achieved are dependent on the material being shocked. In this investigation the maximum estimated pressure was 40 GPa with associated local strains

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of less than 8%. The shock design and parameters allowing the routine recovery of specimens has been given elsewhere.[8]

The Al-Be system is reported as a simple eutectic with low solid solubilities for each element.[9] The enhancement of aluminum diffusion in beryllium by shock was theorized since defects in microstructure can enhance diffusion, particularly if the homologous temperature of the second element is significantly lower than that of the matrix containing the defects. This is the case in the Al-Be system with aluminum having a melting point 0.6 that of beryllium. This implies that the defects in beryllium will not be appreciably annealed out at the temperatures required for aluminum diffusion. The concept was that increased solubility of aluminum would result in higher strength bonds during subsequent solid state bonding of beryllium parts with an aluminum intermediate layer.[10,11]

Experimental

A beryllium rod of 3.0mm diameter was vacuum vapor deposited with aluminum on the outer circumference to a thickness of approximately 10 micrometers. This rod was then inserted into an 1100 aluminum sleeve with an outer diameter of 9.5mm. This was, in turn, inserted into a 304 stainless steel holder. This assembly is illustrated in figure 1. High explosive detonated around the outside of this assembly produced shock pressures from roughly 4 GPa to 40 GPa in the beryllium and associated strain of 0% to 8% at the low and high pressure ends. The post shock samples were heated and the distribution of aluminum in the beryllium was measured by energy and wavelength dispersive spectroscopy in a scanning electron microscope. The heat treat temperatures used in this investigation were 640°C (solid state) and 680°C (Al melt). The aluminum solubility was expected to be greatest in the portion of the sample having the highest defect density as a result of pressure and strain. Figure 2 shows the Be-Al interface region with the beam path and aluminum x-ray profile superimposed. The concentration gradient is shown in more detail in figure 3. The average measured concentration of aluminum away from the interface is 0.05 weight per cent for sample areas shocked at 40 GPa and only 0.02 weight per cent for the sample areas shocked at 4 GPa. These measured concentrations of aluminum in beryllium seem to exceed levels predicted by the equilibrium phase diagram. This portion of the phase diagram has widely varying reported solubility of aluminum in beryllium ranging from nil to 4 or 5 weight per cent near 630°C.[9] It is even possible that the Al-Be system may be immiscible.[12] This variability is also found in other beryllium binary systems and a variety of possible explanations exist. The relative changes in aluminum solubility we have measured are significant. The results are summarized in figure 4. The data is the result of repeated measurements with a ±10% relative variation. It should be pointed out that most of this variation appears correlated to morphology of the beryllium. The actual value, thus, depended on where the measurement was made. The preferential concentration of aluminum near beryllium grain boundaries may indicate that the aluminum was "injected" into the beryllium via the shockwave at the grain boundaries. Alternately, the heat treatment may act to exsolve the aluminum and return the system to the equilibrium state. The estimated residual shock temperature of highly strained beryllium at 40GPa is 288°C.[13] The lower strain of this experiment should reduce this temperature. We do not feel that this temperature effects the observed results.

If indeed, the existing equilibrium phase diagram for Al-Be can be considered a reliable indicator we can only speculate on quasi or non-equilibrium shock effects. At 40GPa in beryllium the estimated adiabatic temperature is 700°C.[13] It is possible, under these combined extreme conditions, that material could be "carried" considerably further into the Be than what would be expected with only a single variable (time or temperature) being applied.

Conclusion

In summary, aluminum solubility in beryllium can be enhanced in a single, uniform specimen by shock activation. The absolute solubility and detailed nature of this enhancement remain to be determined.

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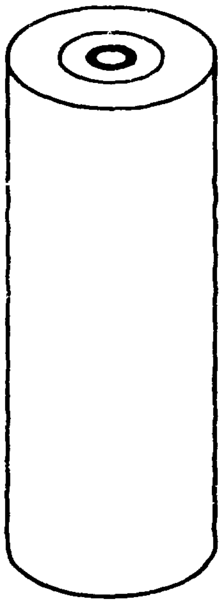
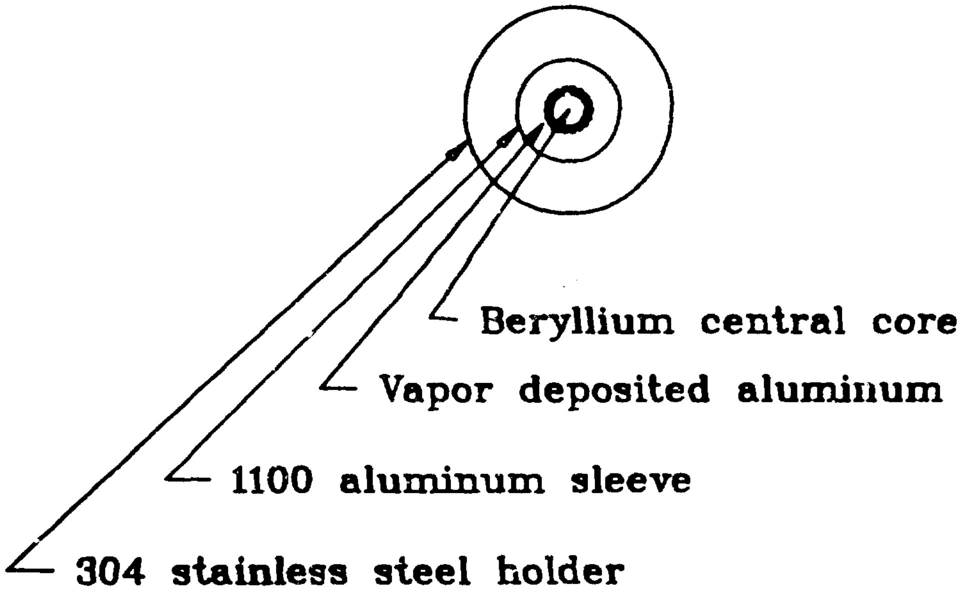
Figure 1. Shock loading assembly showing geometry used for aluminum clad beryllium.

Figure 2. Backscattered electron image of the Al/Be interface. Background subtracted Al x-ray profile shows major Al diffusion (electron beam spread estimated at 0.7μm)

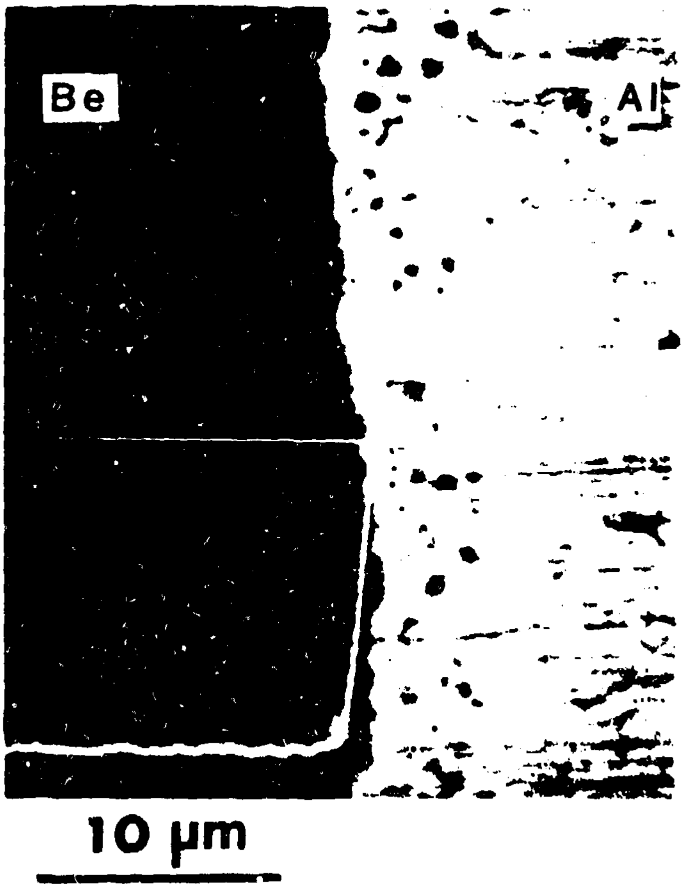
Figure 3. More detailed Al profile across Al/Be interface with result of Monte Carlo beam spread calculation.

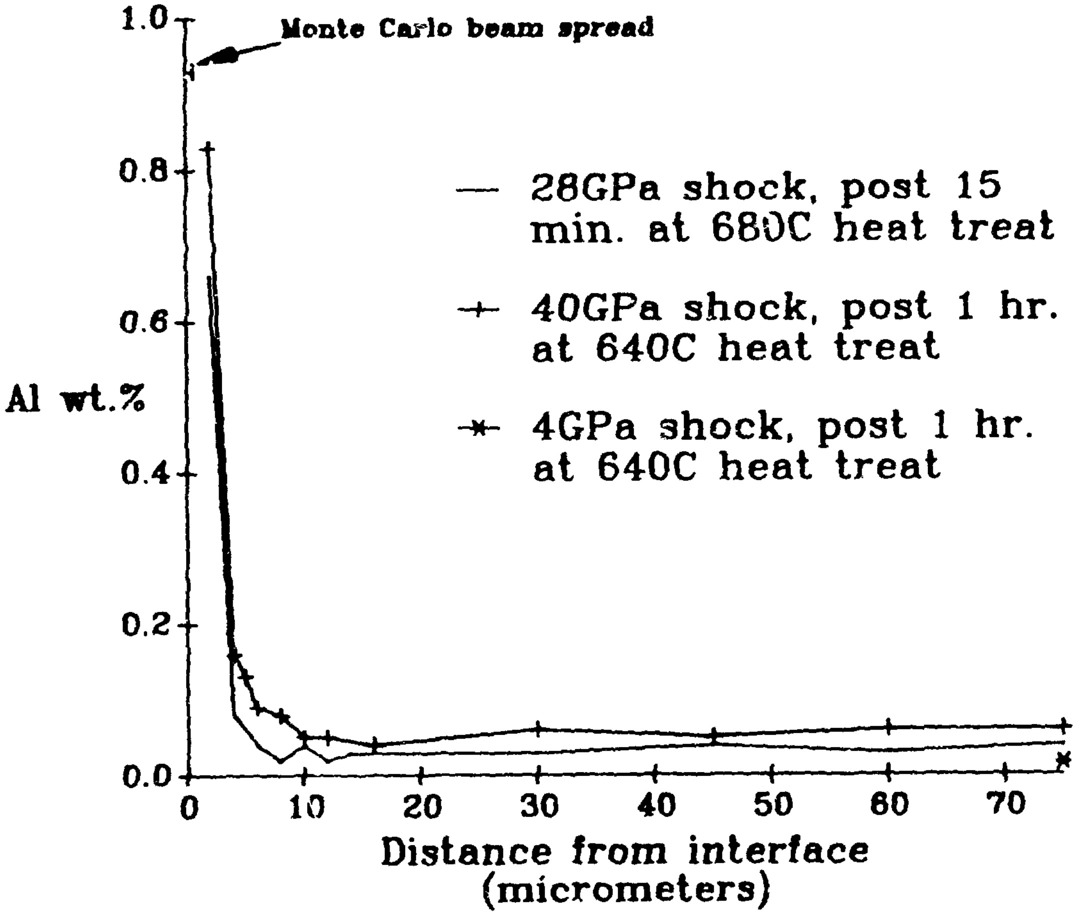
Figure 4. Measured Al solubilities (this study) and published equilibrium solubility.

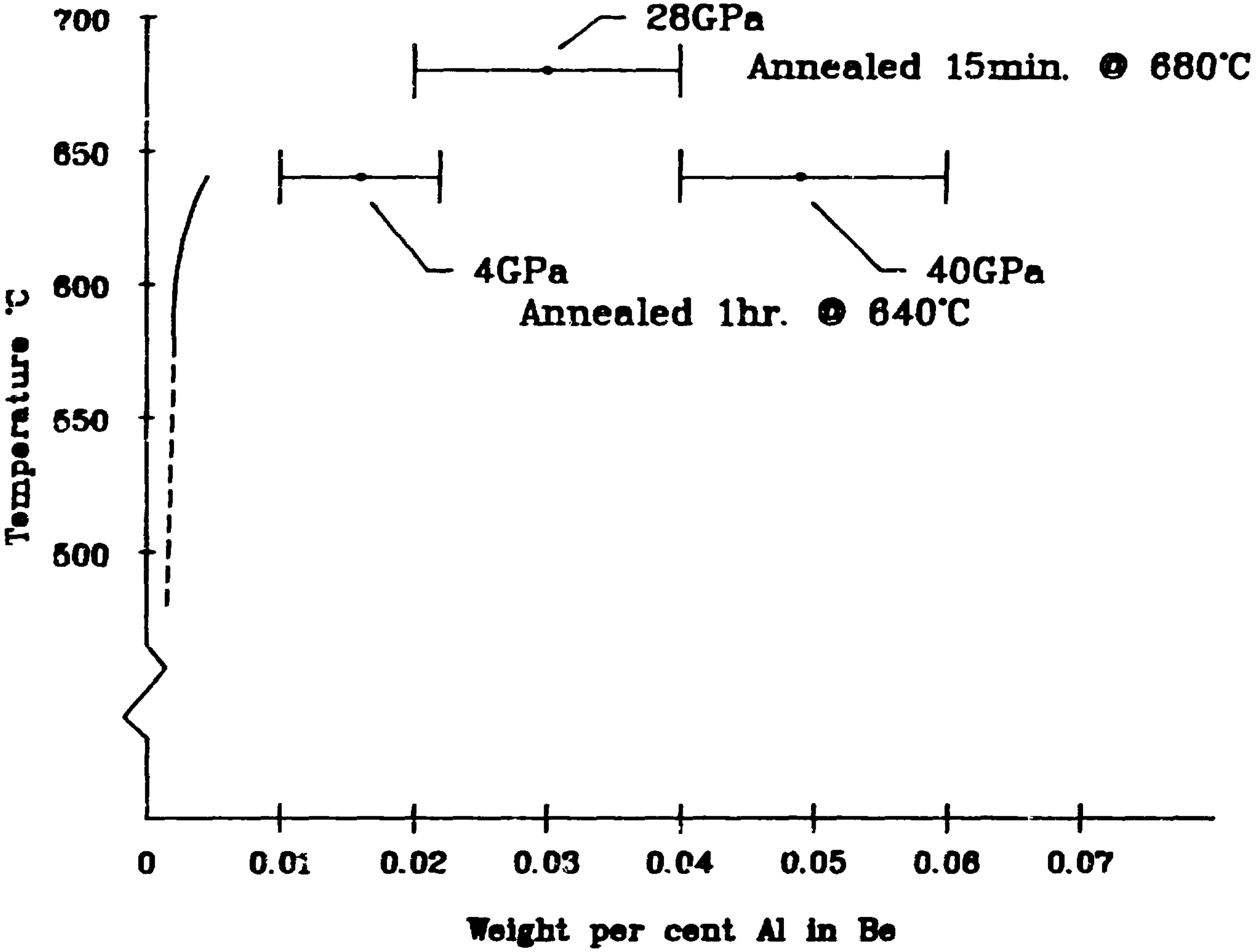




Beryllium central core
Vapor deposited aluminum
1100 aluminum sleeve
304 stainless steel holder


Be
Al
10 μm


1.0
0.8
0.6
0.4
0.2
0.0
Al wt.%
Monte Carlo beam spread
— 28GPa shock, post 15 min. at 680C heat treat
-+- 40GPa shock, post 1 hr. at 640C heat treat
-*- 4GPa shock, post 1 hr. at 640C heat treat
0
10
20
30
40
50
60
70
Distance from interface
(micrometers)


28GPa
Annealed 15min. @ 680°C
4GPa
40GPa
Annealed 1hr. @ 640°C
Temperature °C
700
650
600
550
500
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
Weight per cent Al in Be