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SHOCK COMPACTION, SYNTHESIS, AND CHEMICALLY ASSISTED BONDING OF ALUMINIDES AND SILICIDES§

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Titanium, niobium, and molybdenum aluminides and silicides were compacted using explosively generated shock waves. Both the cylindrical geometry (using a flyer tube) and the Sawaoka geometry were used with the initial temperature of the system varying between 20 and 600°C. Shock synthesis from elemental powder mixtures was obtained for all aluminides and silicides. These shock-induced reactions were used to help the bonding between aluminide and silicide powders. The microstructures generated were analyzed by X-ray diffraction, scanning, and transmission electron microscopy.

1. INTRODUCTION

Intermetallic compounds and their composites are being intensively studied for high-temperature structural applications. They are expected to play a key role in jet engines and other components requiring high strength and oxidation resistance at high temperatures. Shock compression is a technique envisaged to synthesize and process these compounds. Aluminides and silicides were the systems selected. Three classes of experiments were performed and will be described briefly below: (a) shock compaction of powders at ambient and high temperatures; (b) synthesis-assisted shock consolidation of powders; (c) shock synthesis of intermetallic compounds.

2. MATERIALS AND EXPERIMENTAL TECHNIQUES

The intermetallic compounds used in this investigation were titanium aluminide powders (produced by the RSR method developed by Pratt & Whitney), and molybdenum, niobium, and titanium silicide powders (produced by CERAC). Elemental powders, used to shock synthesize compounds, were Ni, Nb, Ti, Mo, Al, and Si. Their sizes were all below -325 mesh (~50 μm).

The shock processing experiments were carried out in four types of fixtures: room temperature cylindrical, high-temperature cylindrical, room temperature planar impact fixture (also known as Sawaoka setup), and high-temperature planar impact fixture. These fixtures are shown in Figures 1 and 2. The cylindrical fixture is described in detail in a number of papers, *e.g.*, Gourdin[1] and Meyers and Wang[2]. The current version of its modification, developed for high-temperature experiments, is due to Ferreira[3]. The capsule containing the powder is pre-heated and placed in the system (left-hand side of Fig. 1). It is then raised by a pulley system, placing the hot capsule inside the explosive charge. Detonation of the explosives is then initiated immediately, at the top. The planar impact assembly (Fig. 3) was developed by Sawaoka and Akashi[4]. The system consists of twelve capsules, that are simultaneously subjected to shock waves that are planar in the die, prior to powder-capsule interactions. This system was adapted for high-temperature compaction by placing the explosive charge on a cart and by constructing a discardable furnace around the capsule-die-momentum trap assembly. After the desired temperature is reached, the cart is translated (by gravity) until it is correctly positioned on top of the capsule assembly.

3. RESULTS AND DISCUSSION

3.1. Shock consolidation experiments

Direct consolidation of titanium aluminide powders (both Ti_3Al and TiAl based compounds) was successfully accomplished in the cylindrical geometry, but was invariably accompanied by profuse cracking. Figure 3(a) shows an optical micrograph of a well consolidated region, in which an interparticle melting layer can be observed. Figure 3(b) shows the cracks that were observed throughout the entire specimens. In an attempt to reduce cracking, high-temperature consolidation experiments were

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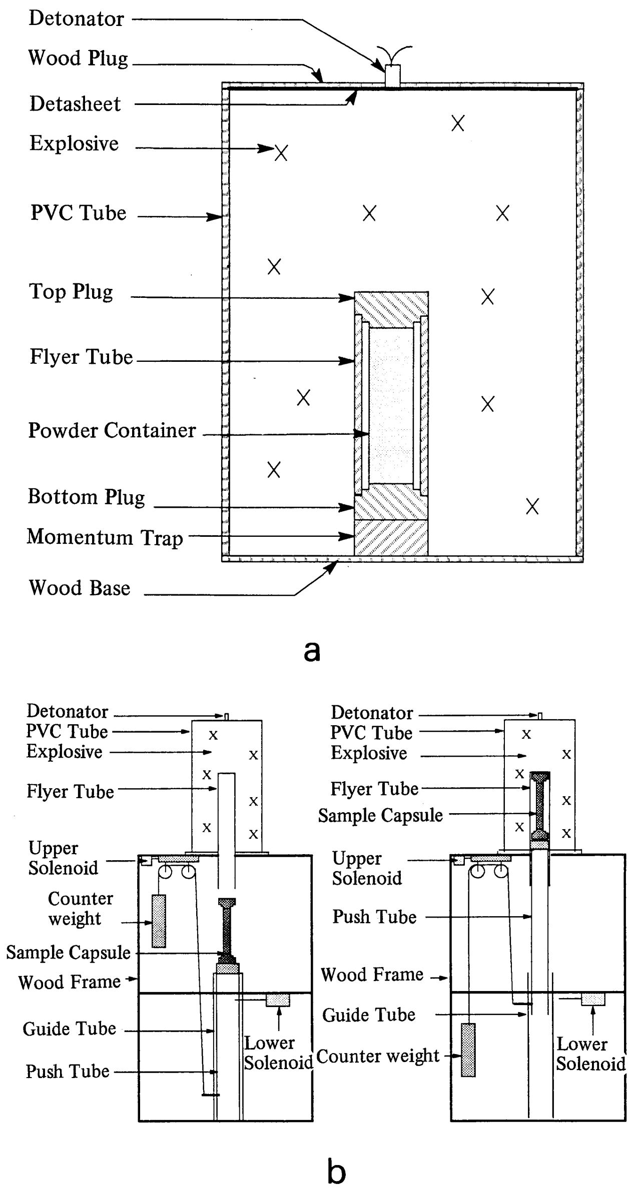

FIGURE 1
Cylindrical fixture using flyer tube; (a) room temperature fixture; (b) fixture for high-temperature experiments.

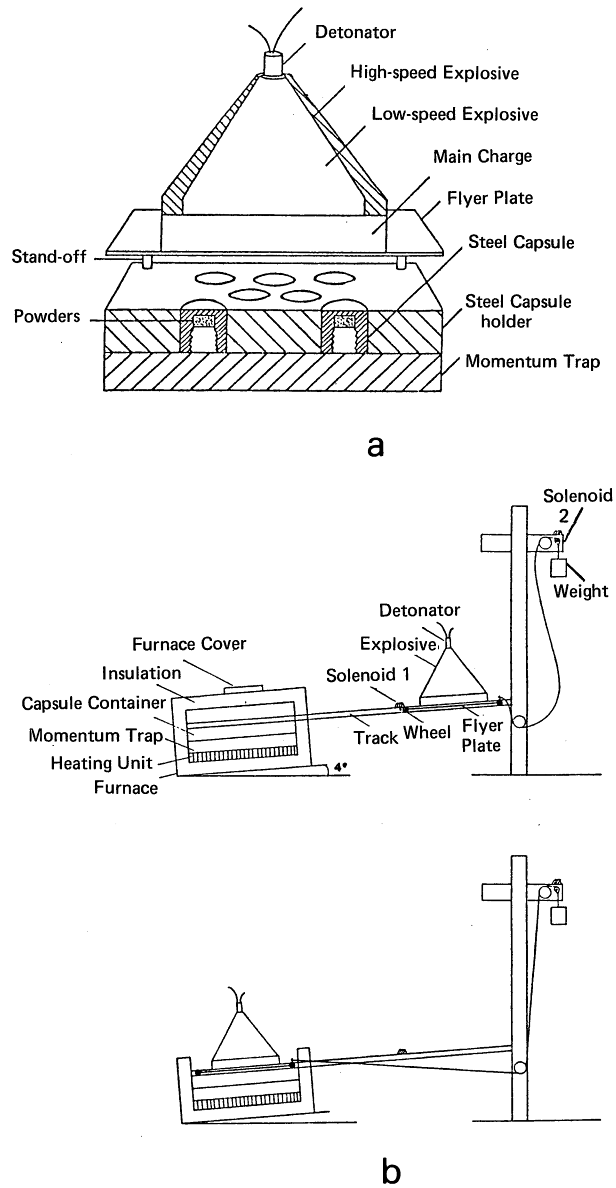

FIGURE 2
Planar impact (Sawaoka) fixture for (a) room temperature and (b) high-temperature experiments

conducted by preheating the specimens to 550°C and 750°C. For TiAl, decreased cracking was observed; for Ti_3Al, increased cracking resulted, by virtue of an embrittling phase transformation in the powder, described in more detail by Ferreira[3]. Ductile niobium powder blended with the titanium aluminide powders was effective in reducing cracking. Figure 4 shows how the more ductile niobium undergoes greater deformation than Ti_3Al and effectively helps bonding. Crack density was also substantially reduced. Transmission electron microscopy of the shock consolidated Ti_3Al powder was performed, revealing amorphous and microcrystalline interparticle regions (from melting and rapid resolidification) and

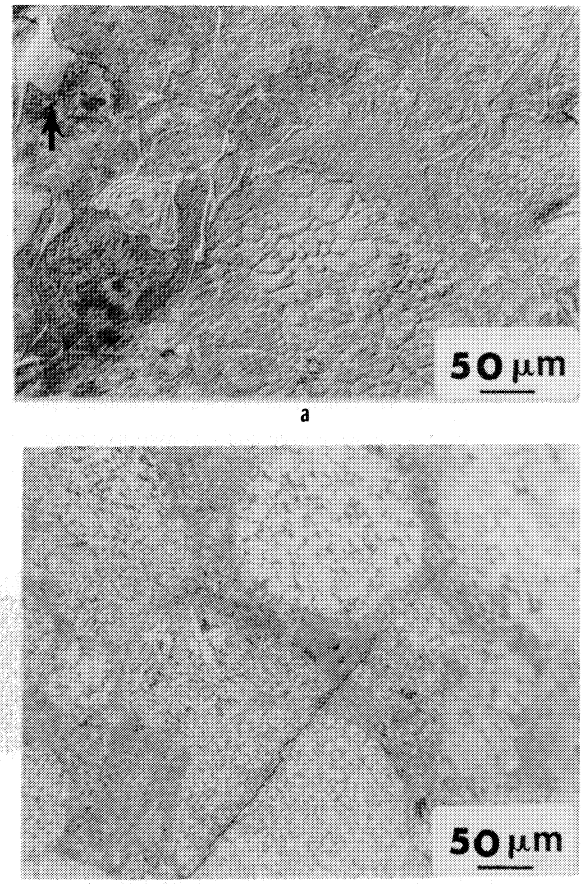

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FIGURE 3
Micrographs of shock consolidated Ti_3Al with evidence of
(a) interparticle melting and
(b) transparticle cracks.

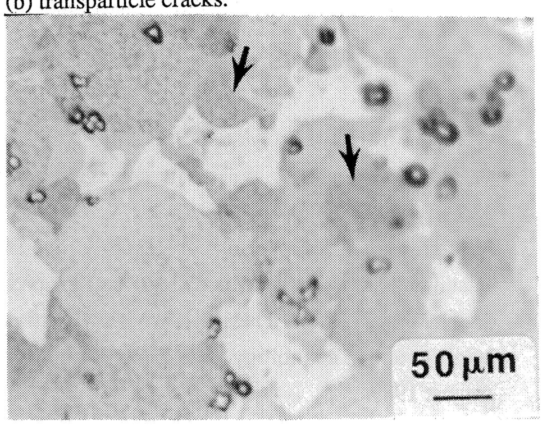

FIGURE 4
Micrograph of Ti_3Al blended with niobium shock consolidated.

a

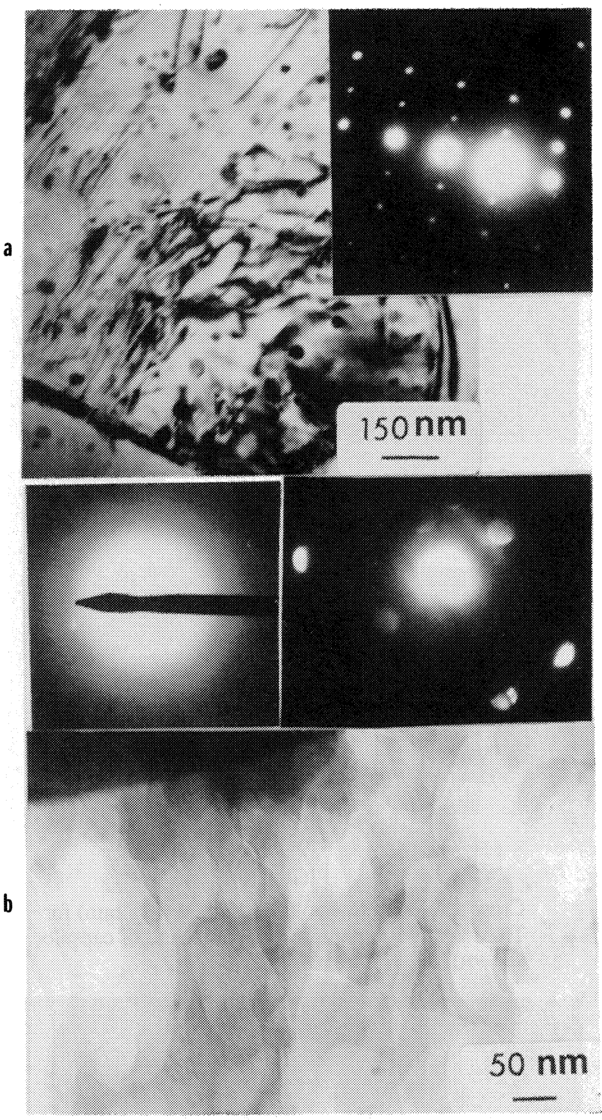

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FIGURE 5
Transmission electron micrographs of shock consolidated Ti_3Al; (a) particle interior;
(b) interparticle melting region, with amorphous diffraction rings.

particle interiors with dislocations, stacking faults, and twins, typical of shock deformation (Fig. 5).

3.2. Shock-induced synthesis

All shock-induced synthesis experiments were conducted in the Sawaoka fixtures. Ti, Ni, and Nb aluminides, and Ti, Mo, and Nb silicides were successfully synthesized. Figure 6(a) shows a Ti-Al while Fig. 6(b) shows a Nb-Si mixture. The bottom portion of the

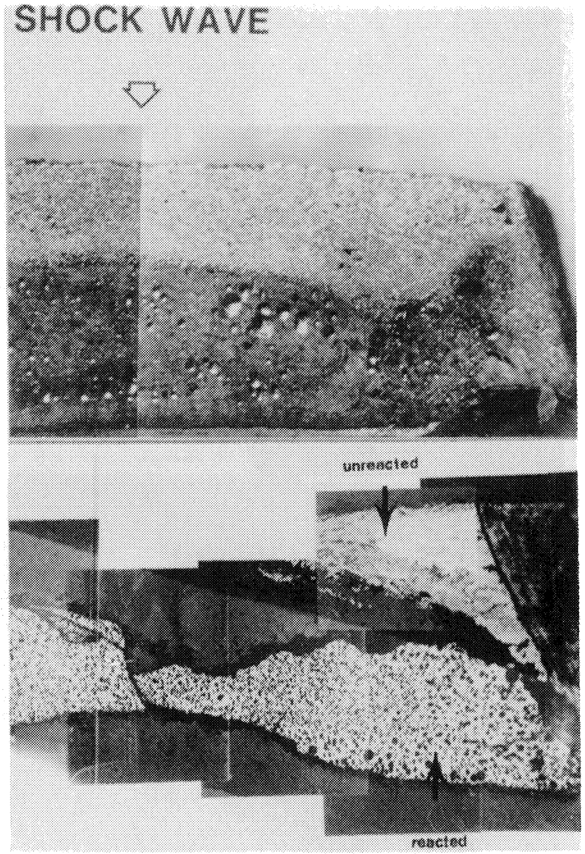

FIGURE 6
Cross section of Sawaoka capsule (ϕ = 15 mm) for Ti-Al and Nb-Si mixtures (only one half of capsule shown).

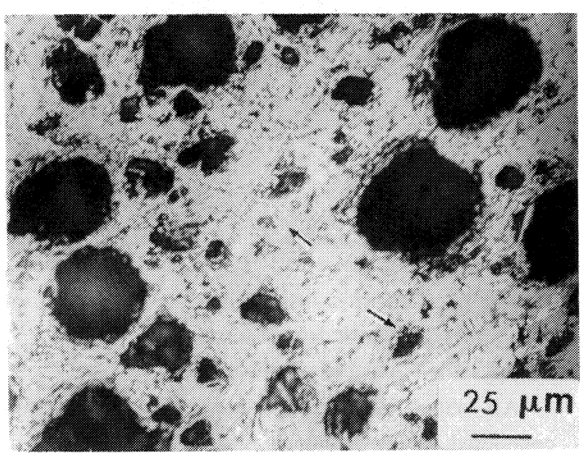

FIGURE 7
Micrograph of reacted region in Nb-Si, showing voids and dendrites.

capsules (where shock pressure and temperature are highest) underwent reaction, at an impact velocity of 2 km/s. The extent of reaction increased with impact velocity and pre-shock temperature. The reacted regions invariably exhibited profuse voids and often a dendritic structure.

3.3 Chemically-assisted shock consolidation

Titanium aluminide and Mo, Nb, and Ni silicide powders were mixed with elemental powders prior to being subjected to shock compression. This technique of reaction-assisted bonding was pioneered by Sawaoka and Akashi[4]. In all cases partial and/or total reaction was obtained (see Fig. 8). When reaction was incomplete, post-shock heat treatments were used and successfully produced completion of reaction. However, profuse voiding was produced. This was solved by hot isostatic pressing of the titanium aluminide samples.

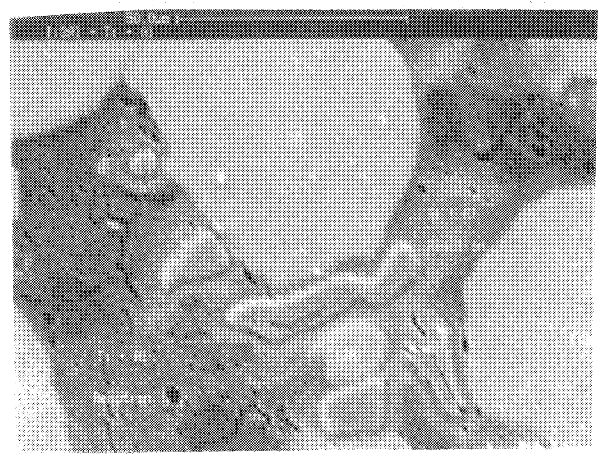

FIGURE 8
Chemically-assisted (Ti + Al) shock compaction of Ti_3Al. Dark regions are reacted regions.

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