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Explosively welded multilayer Ti-Al composites: Structure and transformation during heat treatment

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ABSTRACT

In this study, forty-layered Ti-Al composites were fabricated in a single-shot explosive welding process. The structure of the composites was thoroughly investigated using scanning and transmission electron microscopy. Particular attention was paid to the structure of the mixing zones (vortexes) arising at the interfaces during explosive welding. The complicated process of mixing and rapid solidification of these zones led to formation of different stable and metastable structures. The vitrification of vortexes, formation of "disordered" Ti_3Al and ordered solid solution of Al in hexagonal-Ti and Ti in FCC-Al were observed and discussed with respect to the conditions of solidification. Subsequent heat treatment was carried out at 640 °C under atmospheric and at 3 MPa pressure. For comparison, there were produced reference samples by reaction sintering at the same conditions as for the heat treatment. The heat treatment and reaction sintering promoted the formation of stable Al_3Ti phase between Ti and Al. It was found that preliminary explosive welding accelerated the formation of Al_3Ti layer and made heat treatment duration four times shorter. The application of pressure was found to play an important role at the final stage of heat treatment after explosion welding to avoid formation of defects between the plates.

1. Introduction

In recent decades, Ti-Al intermetallics are receiving considerable attention due to their desirable combination of moderate price, high specific stiffness and strength (due to low density), and chemical resistance at elevated temperatures, which make them attractive for the aircraft industry, rocketry, chemical and mechanical engineering [1,2]. Among several phases allowed by the Ti-Al phase diagram, Al_3Ti (titanium trialuminide) attracts the attention of many researchers as one with the lowest density, highest specific stiffness and oxidation resistance [1,3]. However, the obvious drawback of Al_3Ti, which prevents its application, is the room-temperature brittleness [1,3]. Many attempts have been done to solve this problem by fabricating various composites. Among them, fabrication of aluminum-based composites reinforced by intermetallic particles should be particularly emphasized [4–6]. The main disadvantage of such materials consists in using a fusible aluminum as a matrix material. Recently, several studies have shown that fabrication of metallic-intermetallic laminated (MIL) composites allows extending the application range of Al_3Ti and other intermetallics [3,7–23].

Multilayered materials containing intermetallics resulting from the reaction between titanium and aluminum [3,7–18,24–28], niobium and aluminum [19,20], nickel and aluminum [8,14,21,22,29–31], iron and aluminum [15,16,32–34], aluminum and magnesium [35] etc. are studied intensively. In the majority of analyzed systems, aluminum is used as one of the components. The low melting point of aluminum allows performing the MIL composite fabrication at relatively low temperatures, and low density of aluminum provides low density of intermetallics. Vecchio et al. [3,9,11] showed that, by alternating Al_3Ti intermetallics with Ti6Al4V, it is possible to fabricate a composite with very high specific stiffness and a reasonable level of fracture toughness. In MIL composites, intermetallic inter-layers provide hardness and stiffness while metallic layers contribute in ductility and fracture toughness of the composite. Besides, the presence of interfaces between dissimilar materials causes a sharp change in the crack path direction and renucleation of cracks at each layer, which is another contribution in fracture toughness [8,9,11].

Usually, MIL composites are produced by heating under pressure a multi-layered workpiece consisting of dissimilar metallic foils. These conditions promote the desirable chemical reaction between components. Among the different methods of formation of laminate materials reaction sintering is one of the simplest and the most widespread [3,7–16,24,25,36]. Sintering of Ti and Al foils is typically carried out at a

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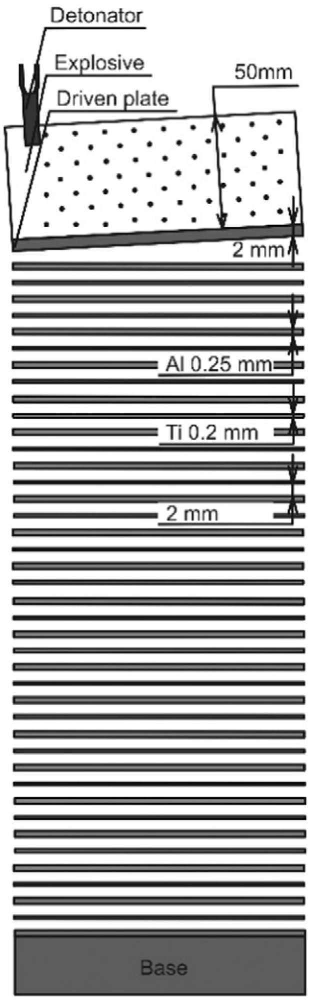

Fig. 1. Scheme of explosive welding.

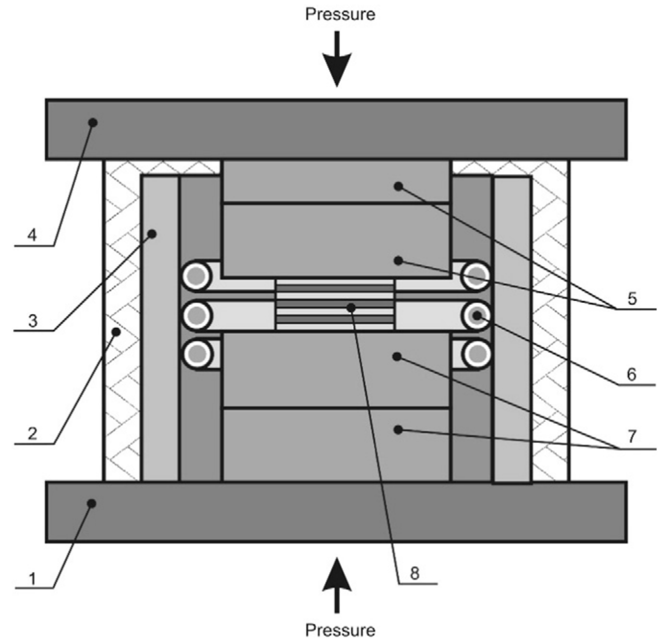

Fig. 2. Scheme of the experimental furnace serving for sintering of multi-layered work pieces under the pressure: 1 — fixed plate; 2 — heat-insulation; 3 — furnace shell; 4 — movable punch; 5, 7 — insulation boards; 6 — nichrome heating elements; 8 — multi-layered sample.

temperature slightly below the aluminum melting point. The technique can be used both in vacuum [8,12–16] and in the air.

In our previous studies [37–39], as well as in studies of other authors [40–49] an alternative method to fabricate multi-layered composites was shown. It consists in explosive welding and subsequent annealing the laminate under normal atmospheric pressure. It was revealed that explosive welding was accompanied by a number of structural transformations at the interfaces between metallic plates. These transformations can contribute to the acceleration of diffusion processes at Al-Ti interfaces.

This study aims to the thorough investigation of interfaces of explosively welded Ti-Al composites and particularities of Al_3Ti intermetallic formation induced by annealing of such composites under an elevated pressure.

2. Materials and methods

Forty-layered composites were obtained from alternately placed commercially pure (CP) titanium (VT1-0) and aluminum alloy (Al-1Mn) plates with dimensions of 100 × 200 × 0.2 mm and 100 × 200 × 0.25 mm respectively according to the scheme shown in Fig. 1. The elemental composition of initial materials measured using ARL3460 optical emission spectrometer is shown in Table 1. Ammonite 6GV powder with density of 0.9 g/cm^3 and detonation velocity of 4.2 km/s was used as an explosive.

Subsequent reaction sintering (heat treatment) of explosively welded composites was carried out according to two regimes. In the first regime, the as-welded composite was annealed at a furnace at 640 °C in the air atmosphere and under a standard pressure. In the second regime in order to investigate the effect of pressure on the process of sintering the heat treatment was carried out in the experimental apparatus shown in Fig. 2. The temperature was 640 °C, and the air atmosphere was used. The pressure of 3 MPa was provided by a hydraulic press ScamexRex 07MI, which was thermally insulated from the furnace. The longest heat treatment time was 20 h.

Reference samples consisting of 21 layers of cp-Ti and 20 layers of Al-1Mn alloy were prepared by reactive sintering process using the same apparatus, shown in Fig. 2. The longest duration of the heat treatment for the reference samples was 100 h.

Structural investigations of the materials were carried out by an optical microscopy method in the differential interference contrast (DIC) regime using a Carl Zeiss Axio Observer Z1m microscope. Cross sections of the samples were grinded by SiC papers with a grain size ranged from 100 to 5 μm. Polishing was carried out using a 1–3 μm-sized alumina powder and a colloidal silica solution with a grain size of 0.05 μm.

The material interfaces were characterized using a Carl Zeiss EVO 50 XVP scanning electron microscope (SEM) coupled with Oxford Instruments X-Act energy dispersive X-ray spectrometer (EDX) in secondary electrons and backscattered electron regimes. A Tecnai G2 20 transmission electron microscope (TEM) equipped with an EDAX EDX system was used to study the fine structure and the phase composition of

Table 1
Composition of initial materials, wt%.

	Ti	Al	Fe	Cr	Ni	V	C	Mn	Si	Cu	Mg	Zn
Ti	Balance	–	0.086	0.017	0.016	0.012	0.011	–	–	–		
Al	0.2	Balance	0.7	–	–	–	–	0.8	0.6	0.15	0.2	0.1