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Original Research Article

The intermetallics growth at the interface of explosively welded A1050/Ti gr. 2/A1050 clads in relation to the explosive material

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ABSTRACT

The effect of heat treatment at 903 K on microstructure and intermetallic compound growth in explosively welded A1050/Ti gr. 2/A1050 clad was presented in the paper. Growth kinetics of $TiAl_3$ intermetallic layers formed at upper and lower interfaces of three-layered A1050/Ti gr. 2/A1050 was investigated. A new approach to definition of growth kinetics of $TiAl_3$ intermetallic phase was discussed. It was established that the growth was solely governed by grain boundary diffusion at the upper interface. Change of the mechanism from grain boundary diffusion to volume diffusion was observed at the lower interface.

1. Introduction

Explosive welding (EXW) is an effective, competitive and low-cost method for fabrication of various industrially useful materials. Multilayered materials composed of alternately placed titanium and aluminum alloys can successfully be manufactured using EXW, except for friction stir lap welding [1], ultrasonic additive manufacturing [2], laser impact welding [3] and accumulative roll bonding [4]. These are for example bimetals: VT1-0/Al AD1 [5], Ti gr. 2/A1050 [6,7], TA2/2A12 [8],

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Ti6Al4V/AlCu4Mg1 [9], Ti6Al4V/AA2519 [10], trimetals: Ti6Al4V/AA1050/AA2519 [11], A1050/Ti gr. 2/A1050 [12,13], TA2/AA6061/AZ31B [14], six-layered arrangements cp-Ti/cp-Al [15,16], seven-layered sandwiches Al 6061/Ti-6Al-4V [17], nine-layered composites TA1/A1060 [18], nineteen-layered materials cp-Ti/cp-Al [19], twenty one-layered set-ups cp-Al/cp-Ti [20] and forty-layered structures VT1-0/Al-1Mn [21]).

In the EXW process of joining one can distinguish the following steps: (1) arrangement of the set-up, (2) detonation of the explosive materials, (3) release of high amounts of energy, propelling flyer plate toward the base plate and creation of the metallurgical bond [22,23]. The EXW can be performed under the both, air [24] and underwater conditions [25,26] in parallel [27] or inclined configuration [28] of ingoing clads with the use of various explosive materials such as: ammonium nitrate mixed with fuel oil (ANFO) [6], ammonite 6 GV powder [21] or trinitrotoluene (TNT) powder [29]. This solid state process is beneficial for joining similar alloys, such as copper/copper [30] or steel/steel [31] and various metals, such as carbon steel/brass [32] or aluminum alloy/magnesium alloy [33,34], which are of great interest for automotive, aerospace and defense industries. Additionally, explosively welded joints can be annealed [35,36] or hot rolled [37] in order to obtain the proper microstructure and thickness as well as new properties (metallic intermetallic laminates). The thermally induced diffusion appears in-between explosively welded metals of Ti gr. 2/A1050 [12,24], A1050/AZ31 [33] and Al alloy/Cu alloy [35] and as a result, the intermetallic phases forming continuous layers of $TiAl_3$ [12,24], Mg_2Al_3, $Mg_{17}Al_{12}$ and $Mg_{23}Al_{30}$ [33] and Al_2Cu, AlCu, Al_2Cu_3 and Al_4Cu_9 [35], respectively can be obtained. The growth kinetic calculations of $TiAl_3$ intermetallic phase [6,12] and a strong relationship of the chemical composition of ingoing clads, the localization of the interface regarding to the explosives and annealing conditions have been previously reported. However, those calculations were performed solely for the compact and dense $TiAl_3$ layers.

The objective of the present research was to study the microstructure of both interfaces of explosively welded three-layered A1050/Ti gr. 2/A1050 clads and to perform the growth kinetic calculations of $TiAl_3$ phase with respect to its localization within the sample taking into account both, the homogeneous layer and the scattered $TiAl_3$ grains randomly distributed at the interface region.

2. Material and methods

Cold rolled sheets of Ti gr. 2 and A1050 were arranged in the parallel mode, as shown in Fig. 1 and explosively welded in one shot in air atmosphere. ANFO, placed on the top of the set-up, was used as an explosive material. The samples (6 × 12 × 2.8 mm) were cut from the central part of the explosively welded clad in order to avoid the edge effect of platters, and annealed in vacuum at 903 K in a chamber furnace. The vacuum was obtained by sealing the samples in quartz ampoules using a rotary pump.

The cross-section surface preparation for SEM/EDS observations was the same as in previous studies presented in [24]. The microstructures and chemical compositions of the samples were identified with the scanning electron microscopy: FEI Quanta 3D FEG equipped with Trident energy dispersive X-ray spectrometer produced by EDAX and PHILIPS XL30 equipped with LINK ISIS EDS system (Oxford Instrument). The standardless analyses were performed at accelerating voltages and working distance of 12 kV and 10.0 mm, respectively. The $TiAl_3$ intermetallic phase area fractions at the interfaces of three-layered A1050/Ti gr. 2/A1050 samples were measured with the scanning electron microscope images by the ImageJ program.

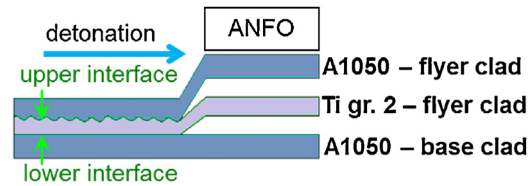

Fig. 1 – Experimental set-up of EXW process of A1050/Ti gr. 2/A1050.

3. Results and discussion

Fig. 2a shows the upper and the lower interfaces of the three-layered A1050/Ti gr. 2/A1050 comopsite, which demonstrated completely different morphologies. The lower interface was located farther back (~0.8 mm) compared with the location of the upper interface from the explosive material, which strongly influenced its morphology. The wavy character of the joint, typical for the explosively welded materials, with intensively swirled intermetallics present at the upper interface changed into planar with no traces of intermediate phases at the lower interface, when examined with SEM. Various shades of gray observed at the SEM/BSE images of the upper interface suggested a complex phase distribution (Fig. 2). The upper interface located closer to the explosive material, was exposed to a greater impact force and, as a consequence, apart from the waviness, was characterized by a significantly more refined microstructure (see TEM image in Fig. 9 in Ref. [24]). There are two fragmentation phenomena, which has been described in the literature, so far. Usually traditional fragmentation is observed after severe plastic deformation, where there is no flying away of material particles. In our case the nano-grains of aluminum (Fig. 9 in Ref. [24]) located at the upper interface region is the result of this process. Among these Al grains, larger and of brighter contrast flying away particles are observed due to the granulating fragmentation (GF) phenomenon described in [38]. GF, which is more likely to appear at the upper interface due to tougher conditions and has a beneficial effect on the formation of intermetallics grains. They are chaotically distributed over swirls and melted areas. As a consequence of heat treatment they converted into aggregations and formed the diffusion zone. On the other hand, the lower interface was of flat mode without melted zones and GF phenomenon. These observations, also reported in [12,24] confirmed that each interface, within the multilayered samples, showed a different phase composition and manifested different starting conditions for their development induced by further annealing process. Furthermore, it was