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Mechanical and microstructural characteristics of Ti6Al4V/AA2519 and Ti6Al4V/AA1050/AA2519 laminates manufactured by explosive welding

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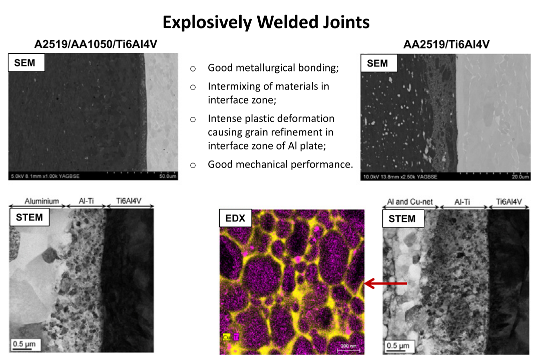
HIGHLIGHTS

- The microstructure and strength of interface joints strongly depends on the presence of additional AA1050 plate
- Good quality of joints was confirmed in tensile testing, as the joints have never been the weakest element of the laminates
- Ti6Al4V/AA2519 and Ti6Al4V/AA1050/AA2519 laminate plates were successfully obtained through explosive welding;
- EXW introduces into both aluminium plates a highly localized plastic deformation, which causes significant grain refinement

GRAPHICAL ABSTRACT



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ABSTRACT

The aim of the work was to produce laminated structures consisting of Ti–6Al–4V alloy and AA2519 plates and to investigate their microstructure and mechanical properties with an emphasis on the role of an additional AA1050 interlayer. Explosive welding was selected as a joining technology. The microstructure and chemical composition of the explosively joined samples were investigated. Mechanical properties were evaluated in the tensile testing and by microhardness analysis.

The results demonstrated that explosive welding is an effective way to produce Ti/Al laminates. Both Ti6Al4V/AA2519 and Ti6Al4V/AA1050/AA2519 laminated plates exhibit good quality of bonding without voids and major delamination. The explosive welding produced metallurgical bonding with a nanostructured zone consisting of Al_3Ti and Al_2Ti phases. This zone is thicker in the joint with additional AA1050 interlayer when compared to direct AA2519/Ti6Al4V bonding. In the latter, SEM and STEM analysis reviled the presence of net-like structure in the collision zone. Advanced EDX analysis shows the enrichment of grain boundaries in copper. The formation of this structure is widely discussed. In addition, the explosive welding introduces large plastic deformation which induces the process of grain refinement in aluminium plates. Tensile testing confirms that joining section is not the weakest element of the cladded plates.

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1. Introduction

The advancements in the aircraft and aerospace industry have been taking place continuously since the middle of last century and are inherently linked with the development and application of new structural materials characterized by the high strength and low density, primarily aluminium and titanium alloys. For aircraft supporting structures, the major requirement for materials to be used is (except lightweight) the fatigue strength and resistance to cracking. However, in the case of special and military structures operated in potentially dynamic interaction with other objects, the high ballistic resistance is also of high importance. In such applications, aluminium alloys cannot fulfil all the requirements, as they feature relatively low strength. In addition, they are excluded from ultrasonic applications due to their limited thermal stability and heat resistance. On the other hand, titanium alloys exhibit the complementary properties such as high strength and high thermal stability. Therefore, in order to combine good thermal resistance and high mechanical properties of titanium alloys with good plasticity and low density of aluminium alloys, a concept of composite laminate material was introduced.

Welding of titanium and aluminium is challenging because they are extremely chemically reactive with oxygen and nitrogen at high temperatures [1]. There are a number of techniques which were specially designed to bond these materials. The one most commonly used is tungsten inert gas (TIG) method, where the weld area is protected from atmospheric contamination by an inert shielding gas (argon or helium) [2]. However, even when using a protective atmosphere, the oxidation process cannot be eliminated in 100%. Therefore, titanium and aluminium alloys should be generally welded using solid-state welding methods. One of such methods is friction stir welding (FSW), where the temperature rise is not higher than a melting point. As a consequence, the formation of pores and second phase particles is suppressed and the embrittlement of joints is avoided [3,4]. However, neither TIG nor FSW allows producing a multilayer laminate material by welding the plates of different materials.

In this context, the explosive welding (EXW) [5] is one of most promising solid-state welding methods because it enables to form the bonding on over the entire junction surface without any oxidation [5,6,7]. It was first described by Carl [8] and proceeds by accelerating the top (cladding) plate to a very high velocity (through the explosion of the coating on its surface) towards the lower (base) plate. The intensive deformation due to high pressure and high temperature generated at the collision point is sufficient to create metallurgical bond. When comparing with other techniques used for joining of metals (such as resistance brazing or welding), EXW has an advantage of permitting two metals to be joined even though they are considered to be incompatible such as aluminium and titanium. Additionally, EXW gives the opportunity to combine the materials characterized by large surfaces or materials with different thicknesses saving their properties after the shot.

The earlier studies on EXW have been focused on the manufacturing procedures, explosive conditions, and bonding strength for various types of joined metals, including Al/Al [9], Al/Cu [10], Al/steel [11] Ti/Ni [12] or Ti/steel [6]. First complex work on joining of titanium with aluminium was reported by Kahraman et al. [13]. The aim of this work was to reduce the weight of the elements while keeping acceptable strength and increased corrosion resistance. Later, a number of reports on cladding of titanium alloys on pure Al, AA1050 or AA6061 were published [7,14–21]. However, to the best knowledge of the authors there is a lack of publications regarding the topic of joining of titanium alloys with stronger age hardenable aluminium alloys, such as Al-Cu ones [22]. Because the properties of such a laminate composite strongly depend on the interfacial structure, it is essential to understand the processes taking place in this zone during the bonding.

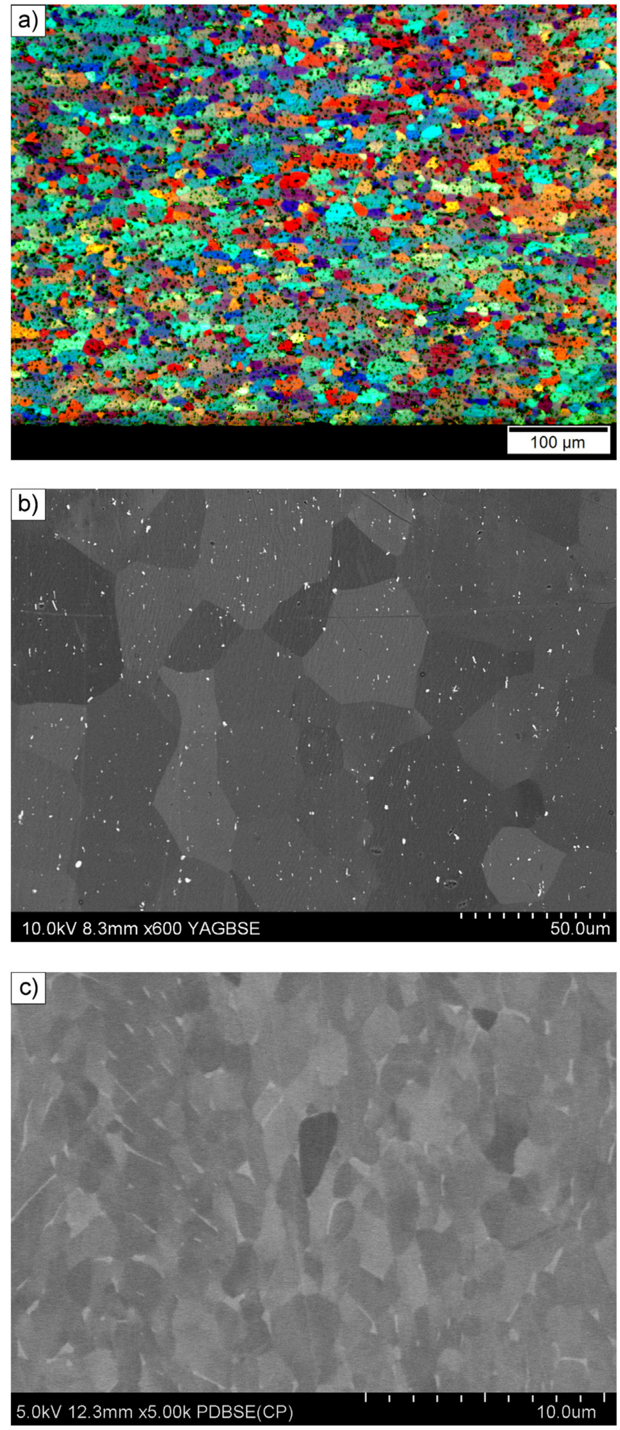

Fig. 1. The structure of initial materials: (a) AA2519 – optical microscope polarized light image, (b) AA1050 – scanning electron microscope, backscatter electron mode, (c) Ti6Al4V – scanning electron microscope, backscatter electron mode.

Table 1
Chemical composition of materials used in this study.

Material	Chemical composition [wt%]							
Ti6Al4V	O	V	Al	Fe	H	C	N	Ti
	<0,20	3,5	5,5	<0,30	<0,0015	<0,08	<0,05	Balance
AA2519	Si	Fe	Cu	Mg	Sc	V	Zr	Al
	0,06	0,08	5,77	0,18	0,36	0,12	0,2	Balance
AA1050	Si	Fe	Cu	Mg	Mn	Ti	Zn	Al
	0,25	0,4	0,06	0,05	0,05	0,05	0,07	Balance