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THE CONCEPT OF IMPROVEMENT HIGH-STRENGTH ALUMINUM ALLOYS FSW JOINT PROPERTIES VIA POST-WELD EXPLOSIVE TREATMENT

Abstract. Although FSW allows to effective join high-strength aluminum alloys, the heat generated during the process causes undesirable changes in the strengthening phase, giving a joint efficiency of about 80%. The potential solution that can limit this problem is post-weld explosive treatment. The main idea is to affect the welded joint by a shock wave generated during the detonation of explosive material, which will increase the hardness of the HAZ.

In recent years, friction stir welding (FSW) has become the subject of many research works due to a number of advantages of this joining technique, including the high quality of obtained joints, the possibility of joining aluminum alloys difficult to weld using conventional methods, low energy consumption and neutrality for the natural environment. Although in the case of pure aluminum and its non-precipitation hardened alloys, deformation and grain refinement in the thermo-mechanically affected zone (TMAZ) and in the stir zone (SZ) increases the strength in these areas, FSW of precipitation-hardened aluminum alloys is characterized by dissolution of strengthening phases resulting in a decrease in strength in each zone: SZ, TMAZ, heat-affected zone (HAZ) [1,2]. These phenomena find their reflection in the distribution of microhardness on the welded joint cross-section (Fig. 1).

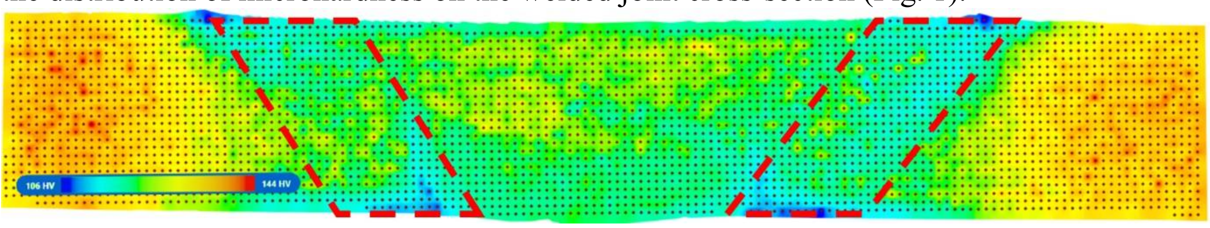

Fig. 1. Microhardness contour map of AA2519-T62 FSW joint [3] with the marked low-hardness zone (red dashed lines).

The zone, which determines the strength of a joint is the low hardness zone (LHZ), often localized on the boundary between the HAZ and TMAZ [1]. FSW joints of precipitation-hardened alloys tend to fail in this zone, which is characterized by low participation of the strengthening phase and coarse grains [4]. In conventional welded joints, the possible solution of this problem is post-weld heat treatment (PWHT) allowing for re-precipitation of the strengthening phases [5]. When it comes to the PWHT of FSW joints there are some problems e.g. in the form of abnormal grain growth, giving relatively poor fatigue properties [6].

In the 70s of the last century, a number of research works showed a significant increase in the strength of welded joints subjected to explosive treatment, especially in terms of fatigue strength [7]. The use of a post-weld explosive treatment may improve the strength of precipitation-hardened aluminum alloy joints as a result of introducing additional defects into the structure by the affection of shock wave. Considering the impact of the shock wave on the HAZ, an assumption can be made that the worst possible case is a complete overage of the precipitates after the FSW process, hence the HAZ would be in the annealed condition. Some works on the explosive welding of high-strength aluminum alloys can be useful to estimate the potential hardening of these alloys during explosive treatment. As an example the explosive welding of AA2519 in the annealed condition can be given, which causes the increase in microhardness from about 75 HV0.1 up to 95 HV0.1 in the area affected by high-velocity collision [8]. For the hardness of LHZ in friction stir welded AA2519-T62 is about 115 HV0.1, potentially it can be increased by a shock wave. It has to be noticed that a shock wave can be generated also by laser shock peening, but it affects only the near-surface area of the joint improving only the fatigue properties without affecting tensile properties noticeably. The generation of the high-amplitude shock wave can be achieved by the use of high-explosive material in the appropriate technological system.

Two factors determine the effect of explosive hardening: the detonation parameters of the explosive material and the used technological system used [9]. From the technological point of view, the post-weld explosive treatment is easiest to perform by "oblique wave", what can be achieved in two systems (Fig. 2a,b).

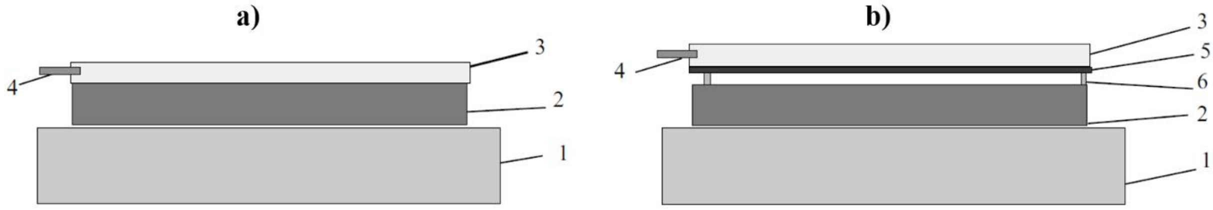

Fig. 2. Explosive hardening systems: direct (a), and with intermediate plate driven by the detonation (b). 1 – base plate (anvil), 2 – hardened plate, 3 – explosive material, 4 – electric igniter, 5 – intermediate (driven) plate, 6 – distance.

In the first case, the shock wave is generated by the direct impact of detonation products (Fig. 2a). The basic parameter of explosive material is the value of detonation velocity. The common industrial explosives used in mining and metal treatment are ammonals, ANFO, emulsion explosives, and plastic explosives, covering the values of detonation velocity from about 1800 to 8300 m/s [10]. It provides wide possibilities for selecting material that gives the highest value of hardening. An additional factor is the thickness of the explosive material layer, which can be optimized in terms of the highest hardening. From the technological point of view, the most suitable form of explosive for the post-weld explosive treatment would be a plastic explosive due to its easy forming and sticking to a welded construction. Nevertheless, plastic explosives are often characterized by a high value of detonation velocity, what can damage a treated element or lead to the generation high amount of heat during the treatment resulting in the overaging of aluminum alloy. The plastic explosives can be modified to severely decreased their detonation velocity by e.g. the addition of ZnO [11], what can be a compromise between accessible form and appropriate detonation parameters for post-weld explosive treatment.

In the second explosive hardening system, the wave is generated by the impact of the intermediate plate which is driven by the detonation products (Fig. 2b). As a driven plate, a simple steel sheet can be used with a thickness of 1-2 mm. Generally, the most efficient hardening is obtained in this system, but there are problems that can limit its application in the post-weld explosive treatment of FSW joints. The system is relatively difficult to construct on the spatial welded structure and there is a risk of explosive welding of the hardened and driven plate. The explosive welding issue can be eliminated by the use of an additional, thin, protective layer (machine oil, plastic), what further complicates the construction. In both systems (Fig. 2a,b), the appropriate base plate (anvil) should be used to limit the deformation of hardened welded plates, what is easy to achieve only in the case of flat, simple welded structures (e.g. butt-welded plate). In more complex welded structures the base plates should be temporarily installed as a part of post-weld explosive treatment or it can be skipped in the

case when the welded plates have high enough thickness (e.g. 50 mm), the layer of explosive material is low and some deformations of construction are acceptable.
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