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Original Research Article

Production of wire reinforced composite materials through explosive welding

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ABSTRACT

Explosive welding is a solid state welding process, which uses a controlled explosive detonation to force two metals together at high pressure. The process has been fully developed with large-scale applications in the manufacturing industry. The explosive bonding technique has an ability to bond a variety of similar and dissimilar materials, and has been applied to fabricate the clad materials and some composites such as multi-layered and wire-reinforced materials. In this study, aluminum plates were explosively welded by placing a steel wire mesh between them in order to produce wire mesh reinforced composite materials. The steel wire meshes were placed at two different orientations (45° and 90°). The wire mesh was used to improve the mechanical properties of the explosively welded aluminum plates. Hardness, tensile strength, toughness, bending and microstructure of the explosively welded composite materials were evaluated. The tensile and toughness tests results showed that the 45° wire mesh reinforced composites exhibited higher strength than unreinforced explosively bonded Al plates. No separation was observed in the interface of the welded composite materials after three-point bending. The highest hardness value was measured for the area near the joining interface.

1. Introduction

The explosive welding (EW) technology was first found by Carl and then was introduced into industry by Phillpchuk. After that, explosive welding technology was deeply studied and widely applied [1]. Currently, a very rapid development of explosive welding is observed [2]. EW is a welding method that welds two or more plates with each other with high pressure coming from explosion. The process, also known as explosive bonding occurs as a result of an inclined crash between two metallic plates. In spite of the occurrence of heat during the explosion, a heat transfer is not observed from one plate to another due to the lack of time [3–5]. The EW process is complex and the quality of obtained composite depends on many parameters. The most important parameters are as follows: the standoff distance (separation distance between the cladding metal and the base metal), the impact velocity, the properties of the bonded metals and the geometry of the welded plates [6–9]. EW is best known for its capability to

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directly join a wide variety of both similar and dissimilar combinations of metals [3,10] that cannot be joined by fusion welding or any other bonding method [11–13]. The process has been fully developed with large-scale applications in the manufacturing industry [13,14]. The bonding technique is also used to manufacture clad metal materials [15].

Explosive welding is mainly used for the production of laminated metals in the form of sheets, rods or pipes in order to improve their corrosion or wear resistance, thermal conductivity or even anti-friction properties [6]. In addition, the explosive welding/cladding is not limited by the types of metals [16]. The EW technique has been applied to fabricate the clad materials and some composites such as multilayered and wire-reinforced materials [3,17–19]. Los et al. [20] produced copper wire reinforced aluminum composite plate through explosive welding method and analyzed the Al–Cu composite properties with intermetallic hardening obtained. In a similar work, Bhalla and Williams [21] produced stainless steel wire reinforced multi layered aluminum composite by explosive welding and investigated the influence of the used wire mesh on the mechanical properties unidirectionally.

Al-based continuous fiber and/or wire reinforced composites find wide usage in areas like aerospace, space automobile sectors and other structural applications [22]. The materials chosen for this work were steel wire and aluminum as matrix material, since both are readily available and their combination would allow the production of a composite with good strength to weight ratio. The purpose of this study is to produce steel wire mesh reinforced aluminum composite plates with improved mechanical properties. In this way, higher mechanical properties are aimed with the use of steel wire mesh. In addition, the steel wire meshes were placed at two different orientations (45° and 90°) relative to the detonation direction in order to examine the influence of orientation on the mechanical properties.

2. Experimental procedure

In this study, commercially pure aluminum plates were bonded by explosive welding method. The bonding was carried out using a steel wire mesh between the plates. In composite plate production, EN 10270-1 2 × 2 × 0.5 mm steel wire mesh was used as reinforcement. The measured tensile strength, percent ductility and hardness values of the aluminum plates (AA1070) used were 95.56 MPa, 7.42 and 40 HV, respectively. Aluminum plates and steel wire meshes were prepared in the dimensions of 300 × 200 × 2 mm. For the explosion tests, a steel anvil plate in the dimension of 1500 × 2000 × 150 mm was used. This anvil plate was placed into a sand pool. Also, a 6 mm thick rubber plate was placed between the anvil and aluminum in order to protect the aluminum from damaging during the explosion. The explosive material prepared was placed in a cardboard box and its top surface was closed. The explosions were carried out by a remotely controlled device. A parallel arrangement (Fig. 1) was used for the joint procedure. Elbar-5 (ammonium nitrate, 5.0% fuel-oil, and 3.0% TNT) was used as the explosive in powder form produced by MKE Barutsan A.S., TR. The explosion rate of the explosive was between 3000 and 3200 ms^{-1}. The initial gap (stand-off distance) between the aluminum plate and steel wire mesh were chosen to be about 2 mm.

Preliminary tests were carried out to determine the suitable amount of explosive used in composite production. Explosive rate of $R = 1$ (equal to the weight of flyer plate ~325 g) was found as the suitable rate. Three different bonds were obtained using the same amount of explosive. Steel wire mesh was not used in one of these bonds. However, steel wire meshes were placed between the aluminum plates in the other two bonds in order to produce composites. The meshes were placed at two different orientations (45° and 90°) relative to the detonation direction (Fig. 2).

To determine the mechanical properties of the bonding, tensile, bending and Charpy test were carried out on the bonded specimens. Three specimens were used for each test in order to determine the mechanical properties of the wire mesh reinforced composite specimens and the results were averaged. Tensile tests were carried out according to EN 10002-1 standard (Autograph-Shimadzu) at room temperature at the speed of 1 mm s^{-1}. Bending tests according to ISO 5173:2000 [23] were carried on a Autograph-Shimadzu instrument. Charpy V notch test specimen is shown schematically in Fig. 3. Three Charpy impact samples for each bonding (unreinforced Al/Al and steel wire mesh reinforced Al/Al composite plates) were prepared and the tests were carried out at room temperature.

Specimens for metallographic observations were cut parallel to the explosion direction from the explosively welded plates and these specimens were mounted in bakelite. Then, these specimens were ground and polished to 3 μm finish. Kellers' reagent (5 ml HF, 10 ml H_2SO_4, 85 ml H_2O) were used as etchant for 20 s. Microstructural characteristics of the explosively

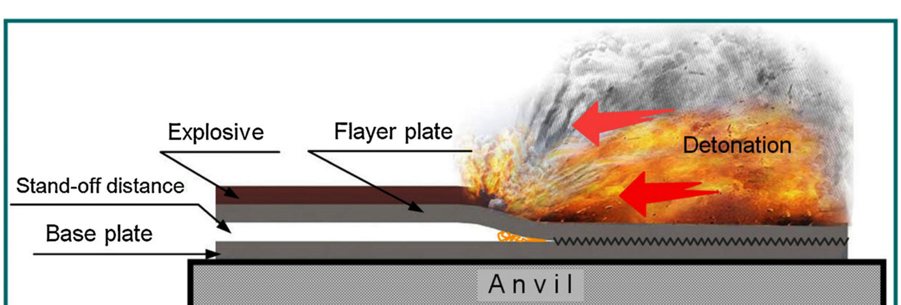

Fig. 1 – The schematic view of parallel set up for explosive welding process.