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High-velocity impact bonding of dissimilar metals by chemically produced hydrogen energy

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Abstract

There has been a growing demand in the fabrication of dissimilar metal parts for application in the automotive, aerospace, defense, chemical and nuclear industries. Welding of dissimilar materials can be accomplished via impact welding, which can minimize the formation of a continuous inter-metallic phase, while chemically bonding dissimilar metals. This paper discusses an innovative technique for bonding dissimilar metals by chemically produced hydrogen energy by reacting aluminum powder and water. Experiments were carried out to bond copper and stainless steel billets. Preliminary test results show the potential of this technique for near-net-shape impact bonding of discrete parts.

Keywords: Explosive welding; Non-explosive impact bonding; Clad composite

Impact welding technologies can be categorized into three groups: explosive welding, magnetic pulse welding, and laser impact welding. All these techniques are considered solid state welding and can be used to join various combinations of metals, including those that are non-weldable by conventional methods such as fusion or diffusion joining. The tenacious surface films of metals, such as stainless steel to chromium-molybdenum, preclude their being joined by roll bonding. Additionally, metals with widely different properties, such as aluminum and stainless steel, can be joined by impact welding. Metals having widely different melting points, such as aluminum (660 °C) and tantalum (2995 °C), can also be impact welded. Among the types of impact welding, explosive welding is widely used in industry. It is a well-developed technology and ideally suited for welding of large flat plates (Fig. 1). The major limitations of explosion welding are: The process requires extensive safety procedures because of the inherent hazard of storing and handling explosives; Because of the safety concerns associated with explosives, and their higher noise emission, explosion welding is generally performed in isolated facilities by companies specialized in explosive operations; The intense dust created compromises the air quality around the facility, thus workers are usually required to leave the facility for 12–18 h following explosion welding; Although this process is ideal and economical for producing large products that require dissimilar materials, the process may not be ideal for producing smaller discrete parts because the bonded plates are used as raw material for producing discrete parts via machining operations, resulting in substantial material wastage in the machining operations.

Recent alternatives to explosive welding for small and medium parts include impact welding techniques based on magnetic pulse welding and laser impact welding. Magnetic pulse welding can be used to weld parts with ease. However, the parts should be electrically conductive. Also,

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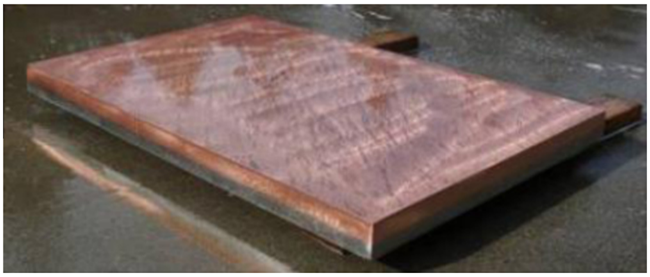

Fig. 1. Explosive welded plates [1].

the consumption of electric energy grows significantly as the weld line lengthens [2,3]. Laser impact welding is used for thin foil and does not require the flyer materials to be electrically conductive [2,4]. In magnetic pulse welding, electromagnetic force is used to accelerate the flyer plate. The process is based on Faraday's law of electromagnetic induction, resulting in repulsive Lorentz body forces between two conductive bodies carrying opposite current [5]. Since electromagnetic power is used, the desired loading conditions can easily be implemented by controlling the electric power supply. The mechanisms of bond formation for magnetic pulse welding have been observed to be identical to those for explosion welding [6]. One of the limitations of magnetic pulse welding is the fact that the process can be used only for conductive materials and that the process is most suitable for materials with a high electrical conductivity [7,8]. The smaller the electrical conductivity of the workpiece, the more energy will be transferred into joule losses [9].

This paper discusses an innovative technique for impact bonding of dissimilar metals by chemically produced hydrogen energy by reacting aluminum powder and water. Advanced Hydrogen Technologies Corporation has developed a cartridge based system that can produce enormous hydrogen power instantly via aluminum-water reaction [10,11].

Table 1
Potential metal–water reaction for production of hydrogen [12].

Reaction	Heat release per unit mass of metal (kJ/g)	Hydrogen release per unit mass of metal (cm^3/g)
$Li + H_2O = LiOH + 1/2H_2$	28.77	1600
$Na + H_2O = NaOH + 1/2H_2$	6.08	487
$K + H_2O = KOH + 1/2H_2$	3.58	286
$Mg + 2H_2O = Mg(OH)_2 + H_2$	14.71	933
$Ca + 2H_2O = Ca(OH)_2 + H_2$	10.35	559
$Al + 3H_2O = Al(OH)_3 + 3/2H_2$	16.95	1244

1. Impact bonding of dissimilar metals by chemically produced hydrogen energy

The reaction of metals and water is a potential source of hydrogen energy. Table 1 lists several such reactions, one of which involves water with aluminum powder. Besides relatively high energy and large hydrogen release, this reaction is desirable also because its condensed product, aluminum oxide/hydroxide (Al $(OH)_3$), is environmentally benign [12–15]. Moreover, aluminum oxide byproducts have numerous industrial applications such as making of alumina, water treatment of flame retardant and recycling the oxide to produce metallic Al [16]. Aluminum is relatively inexpensive and is not reactive in air at ambient conditions. The large amount of hydrogen released indicates the potential of an Al/H_2O system as an energy source for different applications, including powering machines for manufacturing processes.

Research on hydrogen production as a source of energy is actively pursued by many researchers due to its potential in fuel cells, automotive propulsion, marine propulsion, etc. The main problem associated with aluminum–water reaction is the existence of oxide protection film on the aluminum particles' surface, which does not dissolve, hence slowing the chemical reaction. To enhance the chemical reaction of an Al/H_2O system, researchers have studied the influence of different parameters such as (a) water temperature, (b) activators, (c) aluminum particle size, (d) aluminum water mass ratio, and (e) type of water.

Experiments have shown that the rate of reaction of aluminum in water is strongly dependent on water temperature. Activators are employed to make the surface of oxide film of aluminum particles non-protective. The use of activators can results in 100% yield of hydrogen. Mohamoodi et al. [13] milled aluminum together with salt at a mole ratio of 2. Through this activation procedure, aluminum could be hydrolyzed quickly, with 100% yield of hydrogen release. Due to hydrogen's low molecular weight, it "out speeds" all other gases, which makes it an

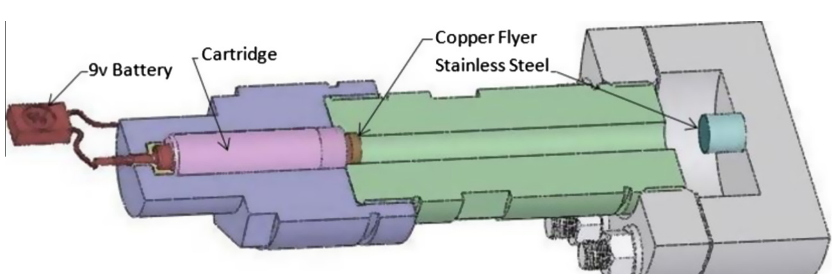

Fig. 2. Experimental setup.