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Process analysis for magnetic pulse welding of similar and dissimilar material sheet metal joints

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Abstract

Magnetic pulse welding (MPW) is an impact welding technology for producing metallic bonds of similar and dissimilar materials offering advantages such as avoidance of temperature induced problems. Based on the parameters describing the collision of the joining partners, specifically the impact angle and impact velocity, so-called welding windows describe whether or not welding will be successful for a specific material combination. However, as in MPW collision parameters depend on equipment and setup dependent parameters, using these welding windows for process design requires knowledge about the adjustment of the collision parameters via the adjustable process parameters. Therefore, the influence of adjustable process parameters on collision parameters and resulting weld quality is analyzed and trends, for a target oriented process and joint design, are deduced. Specifically, joining of copper to aluminum, copper to copper, aluminum to copper and aluminum to stainless steel is regarded.

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Keywords: Magnetic pulse welding, Process analysis, Multi-material joints

1. Motivation

Rising awareness of responsibility for environmental protection and saving of energy and resources in society and politics which is fixed in national and international laws and agreements as e.g. the Agenda 2030, increasingly influences industrial manufacturing. This manifests e.g. via the increasing demand for lightweight construction

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approaches. For many years multi-material design has been a well-known strategy that allows weight savings, higher product performance and cost reduction at the same time [1], [2], but the realization of optimized multi-material products is frequently limited by the joining technology. Conventional (thermal) techniques reach their limits when it comes to joining of material combinations featuring significantly different melting temperatures or tending to form brittle intermetallic phases such as aluminum and stainless steel or copper and aluminum.

2. Fundamentals of magnetic pulse welding

Magnetic pulse welding (MPW) is an innovative technology for producing metallic bonds of similar and dissimilar metals. The setup of the process, which is based on the electromagnetic forming technique, consists of the inductor (i.e. the tool), the pulsed power generator (i.e. the machine), the flyer (i.e. the accelerated joining partner), the target (i.e. the static joining partner) and additional elements ensuring that flyer and target are positioned with a defined small gap $g_{initial}$ in-between them (see Figure 1a). As explained in [3] discharging the capacitor of the pulsed power generator via the inductor generates a time-dependent current $I(t)$ in the inductor and a corresponding electromagnetic field. This induces a second current in the flyer. The interactions of the currents and the magnetic field result in Lorentz forces, which accelerate the flyer to velocities of up to some hundred meters per second towards the target and make the two joining partners collide with each other as shown in Figure 1b. The initial gap between flyer and target, which is indispensable for the process, significantly influences both, the available space for accelerating the flyer and thus the achievable impact velocity and the impact angle of flyer and target. If these parameters are suitable, a metallic bond is formed without largely heating the parts. Thus, temperature induced problems of conventional welding such as heat distortion, forming of intermetallic phases and thermal softening are avoided and high-quality joints can be achieved. The process requires no additives and shielding gases, it is flexible, shows good reproducibility and high automation potential [4]. Feasibility was proved for multi-material welds as e.g. aluminum and iron, nickel and copper [5], aluminum and steel [6], or aluminum and titanium [7]. This shows high freedom regarding material combinations, but it must be considered that the process principle requires high electrical conductivity of the flyer.

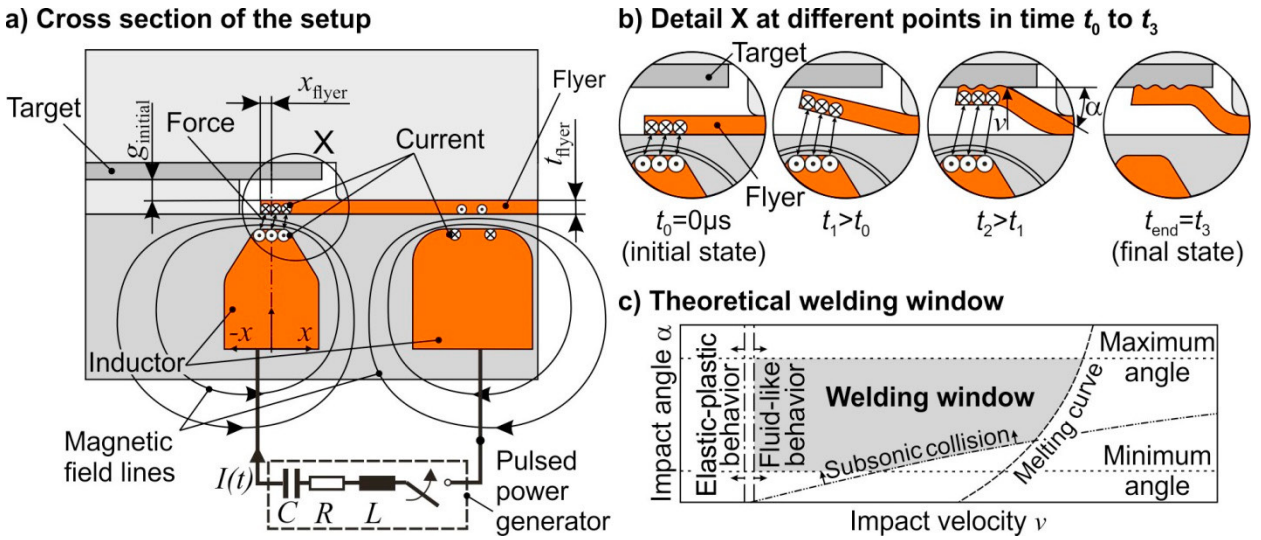

Figure 1. (a) Cross section of the setup; (b) Forming states; (c) Theoretical welding window according to [8]

In literature, collision parameter based welding windows are suggested as a process design tool for MPW. They indicate if welding results for a specific constellation of impact angle and impact velocity (see Figure 1c). Such welding windows are well-known from explosive cladding, another but with regard to safety issues much more critical impact welding technology, but direct transfer of the process windows quantified for explosive cladding to