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Development of a novel test rig to investigate the fundamentals of impact welding

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ABSTRACT

Despite the great technological advantages of impact welding, its application is still not widely spread. One reason is the poor understanding of its mechanisms and the effects on the bond strength. In this paper, a novel test rig is presented, which allows the straightforward investigation of impact welding and its basic principles to help filling this gap of knowledge. Impact angle and velocity, which are known to be the most important process parameters, can now be freely and almost independently varied over a large range of values. The built-up of the test rig and its functionality will be presented in this paper. Furthermore, first numerical and experimental results will be discussed and compared to an industrially implemented process. The investigations show that the test rig is capable of representing the high-speed collision of the real process.

1. Introduction and motivation

Material-closed joints of high strength, without any heat-affected zone and almost free of intermetallic phases even between dissimilar metals can be created during a high-speed collision of two workpieces. Industrial implementation is already possible with electromagnetic pulse welding (EMPW) and, to a certain extent, with explosion welding (EXW). These processes use strong electromagnetic forces or powerful blast waves to accelerate the workpieces to the desired speeds, which can exceed the speed of sound in air. Their main drawback is the poor understanding of their governing fundamentals. Besides the great technological advantages, both processes share the difficult investigation of their principles. The main reason is the limited observability due to the blast waves of explosion welding or the transience of electromagnetic pulse welding. The novel test rig is designed to avoid these limitations and allow a simple observation of the process as well as the controlled variation of process parameters. Whereas other systems have a complex built-up (Akbari Mousavi and Al-Hassani, 2005) or do only reach minor speeds below 100 m/s (Psyk et al., 2012), this test rig is capable of achieving collision speeds up to 300 m/s at almost constant angles with a simple, purely mechanical set-up.

2. Process principles

Impact welding usually requires the presence of two workpieces in close distance: The so-called flyer is accelerated towards the so-called target. The short distance between the two workpieces is needed for the acceleration. The collision speeds are usually roughly in the range between 200 m/s and 600 m/s for both EXW (Crossland, 1982, pp. 93) and EMPW (Elsen et al., 2011). Oxides and superficial impurities are removed from flyer and target due to the great plastic deformation during the impact. They are driven out of the closing gap together with the ambient air as the so-called jet. To obtain a joint, two parameters are known to be crucial from previous studies in explosion welding: The two joining partners have to collide at a certain angle (often referred to as β) and the line of the first contact travelling across their surfaces needs to have a certain velocity (often referred to as v_c). Both angle and velocity have to be set according to the material combination. The material combination in turn influences angle and velocity due to the mechanical properties of the joining partners, which has to be compensated by carefully adjusting the process parameters. Fig. 1 schematically depicts the two most popular and industrially applied representatives of impact welding: EXW and EMPW.

EXW uses the energy of a blast wave created by explosives, whereas EMPW uses the energy of a strong, pulsed magnetic field,

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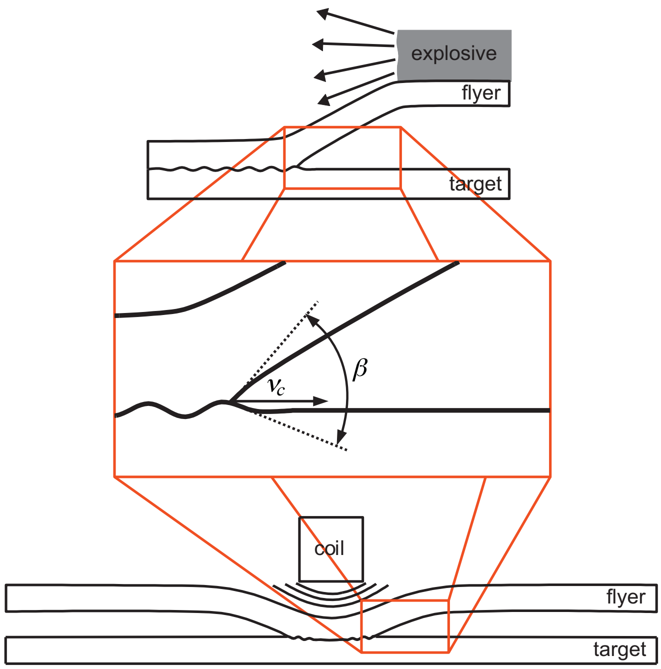

Fig. 1. Top: Typical configuration for EXW (Carpenter and Wittman, 1975). Centre: Angle and velocity of the collision point. Bottom: Typical configuration for EMPW.

which is created by the discharge of high voltage capacitors through a coil. The main difference between these two methods is the available amount of energy to accelerate one workpiece. EXW allows the processing of large plates with a surface area of up to several square metres, for example for vessels, whereas EMPW is often limited to line-shaped joint areas. Nevertheless, it is more suitable for industrial mass production because it does not involve potentially dangerous explosives and allows cycle times in the range of seconds. As multi-material design becomes more and more relevant due to the demand for a resource saving production and weight reduction in load oriented designs, the focus moves from conventional joining processes to EMPW.

The main drawback of EMPW is the poor understanding in the underlying principles, which leads to an almost exclusively empirical process design. For EXW, which is few decades older, process windows for various combinations of materials have been identified (Grignon et al., 2004; Crossland, 1982). These process windows are commonly shown in diagrams where the angle β between the two joining partners at the collision point is plotted over the velocity of the collision point v_c. Fig. 2 exemplarily shows a qualitative process diagram with known process boundaries. When the upper process boundary is exceeded, molten areas can be observed because the impact energy is too high. Under the lower process boundary, no joint is possible. When the velocity of the collision point is too high, the jet cannot escape from the closing gap and is hence trapped in the interfacial layer and prevents a material-closed joint.

In EXW, where larger areas are bonded, a much more constant collision point velocity and angle for the particular material combination can be set. The correct amount and type of explosive have to be chosen and the initial distance between the two workpieces has to be set. In EMPW, angle and velocity constantly change while the collision point travels across the collision area, as shown in the simulation part of this paper. The material-closed joint only occurs where both parameters are inside the process window, which leads to the characteristic line-shaped joint area. To summarize, EXW on the one hand shows constant velocity and angle but offers bad observability due to the explosives. On the other hand, EMPW is

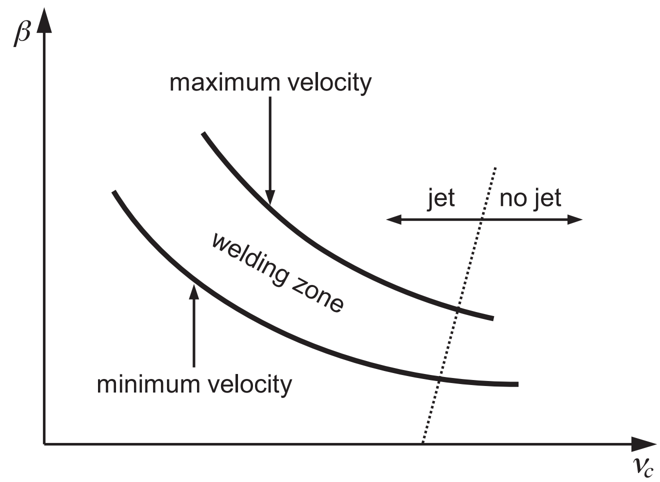

Fig. 2. Welding window with process boundaries (Crossland, 1982).

easy to observe and easy to conduct, but the process is highly transient. So far, there has not been any satisfying possibility to combine the advantages and to avoid the disadvantages of both processes.

3. Test rig

To overcome the limitations of EXW and EMPW concerning their suitability for basic investigations, a novel test rig has been developed at the Institute for Production Engineering and Forming Machines (PtU). It combines the advantages of EMPW (secure and easy to conduct) and EXW (constant velocity and angle) in a simple and purely mechanical set-up.

3.1. Design and structure

The test rig is depicted in Fig. 3 and mainly consists of two solid steels shafts which are driven by one controlled synchronous motor each. Motors and shafts are connected via couplings of high torsional stiffness. Table 1 gives detailed information on the motors and their frequency converters. The frequency converters of the motors are linked together via EtherCAT and contain a control unit. Clamping units are attached at the opposite end of the shafts and hold the rotors made of aluminium tubes. One specimen is attached to one end of each rotor (Figs. 5 and 6). At the opposite end, a counterweight with the mass of the specimen is mounted. In order to reduce their weight and therewith moment of inertia as much as possible, specimens and counterweights are held by one screw each and kept in place in the tube by a plastic inlay.

The aluminium tubes are designed considering three effects: Bending moments caused by air resistance, tensile forces due to centrifugal forces and their moment of inertia. All three have to be as little as possible, which can be achieved by a careful adjustment

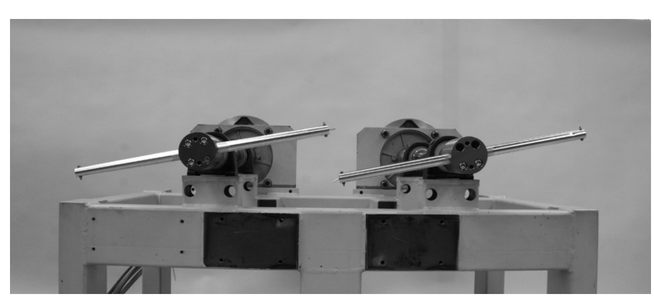

Fig. 3. Image of the test rig (without housing).