Magnetic pulse welding of multi-material connections at high velocity and without temperature influence

Copper excels due to its high electrical and thermal conductivity as well as due to ist excellent chemical stability. Due to these properties it is currently the thirdmost used raw material in Germany and in the world [1] [2]. Especially in applications related to HVAC as well as in electrical applications it is indispensable. Accordingly in 2014 nearly 60% of all copper material processed in Germany was used for cables and electrical applications and further 15% were applied in civil engineering.
Due to the fast developments in the electronics sector the copper demand has been increasing over the last years and the copper price has been rising accordingly (Figure 1a and b). Another disadvantage, which must be accepted when using copper is the extremely high density of this material, which leads to high component weight and contradicts current trends of lightweight design.

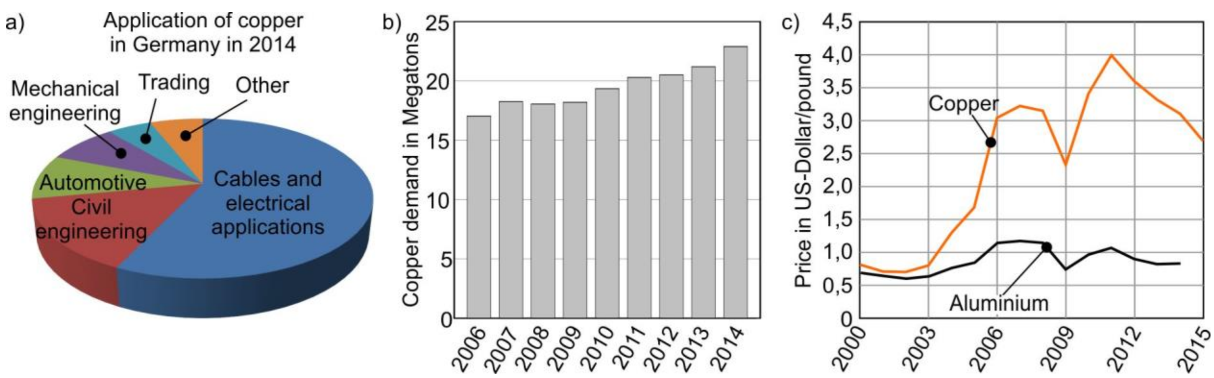

Figure 1 Copper demand, price, and application case according to [2]

For economic and ecological reasons and in some sectors as e.g. the automotive industry also due to legal requirements related to reduction of emissions, it is desirable to substitute copper by an alternative material as far as possible. Here especially aluminium is a good candidate, because its electrical and thermal conductivity is about 60% of that of copper, while costs per weight unit are only about 40% and density is even only about 30% of the according values of copper.

Against this background, the JOIN'EM project, funded by the EC has been established. In JOIN'EM 14 partners from industry and scientific institutes coming from Germany, Austria, France, Belgium, Italy, and Spain are researching together under the coordination of the Fraunhofer Institute of Machine Tools and Forming Technology – IWU to replace parts, which are currently made from copper completely by hybrid aluminium copper parts. These will consist mainly of aluminium while copper is maintained only in regions where it is indispensable, e.g. as a thin layer. Thus, significant cost and weight savings are possible. However, this approach requires a suitable technology for the economic manufacturing of high quality aluminium copper joints. Here, magnetic pulse welding, which is based on the so-called electromagnetic forming, is a good candidate.

The basic setup for magnetic pulse welding is shown in Figure 2 for joining of tubes and in Figure 3 for joining of sheet metal parts. It consists in both cases of a pulsed power generator (represented in the figures by the equivalent circuit diagram consisting of a capacitor battery C an inner inductance L_i and an inner resistance R_i), the tool coil (frequently called inductor), which is geometrically adapted to the specific joining task, the joining partner to be deformed (Flyer) and the static joining partner (Target).

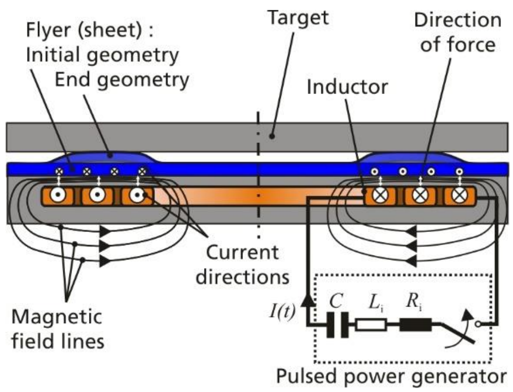

Figure2 Process principle of magnetic pulse welding of tubes

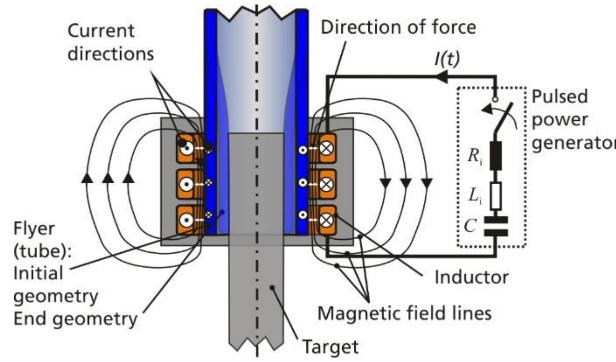

Figure 3 Process principle of magnetic pulse welding of sheet metal

For the joining process the ends of flyer and target are positioned in a defined distance and overlapping each other. The capacitor of the pulsed power generator is charged with defined energy and discharged via the tool coil, so that a damped sinusoidal current pulse flows. This time-dependant current induces an according magnetic field and a second current in the flyer, which is directed opposed to the coil current. Due to the interactions of magnetic field and current Lorentz forces occur in the flyer, which result in a plastic deformation directed away from the coil as soon as the flow stress of the material is reached. This is the so-called electromagnetic forming. After overcoming the initial distance between flyer and target, collision of the two joining partners occurs. If the collision parameters are within a process window, which depends on the material combination to be joined, metallically bonded joint results.

For magnetic pulse welding it is essential that the joint is produced as a consequence oft he high-speed collision without significant heating of the part and consequently without temperature related problems of conventional welding processes as e.g. heat distorsion and strength reduction in the heat affected zone. Additionally, the formation of intermetallic or oxydic phases is reduced significantly so that it has no negative effect on the joint quality. Thus, material combinations, which are not possible with convential methods, become possible. Moreover, no shielding gases or additives are required. Due to the relatively low binding of the tools to the specific manufacturing task, the process is very flexible and additionally it excels due to high reproducibility and automation possibilities, comparably short process times and low energy consumption [6].

One focus of the research in JOIN'EM is put on technology development for welding of sheets. The aim is to determine the influence of adjustable process parameters on the joint formation and the resulting joint quality by a combined numerical and experimental parameter study, and based on this to derive guidelines for the process.
Within this study, it was shown that in case of clever processing the produced joints excel due to high strength. In lap shear tests performed on magnetic pulse welded copper aluminium hybrid sheets failure occurs in the copper base material in significant distance to the joining zone (see Figure 4), which clearly shows that the joint strength is higher than the strength of the weaker initial material.

Here, this is the copper sheet, which has a significantly lower wall thickness (0.5 mm) compared to the aluminium (2.0 mm).

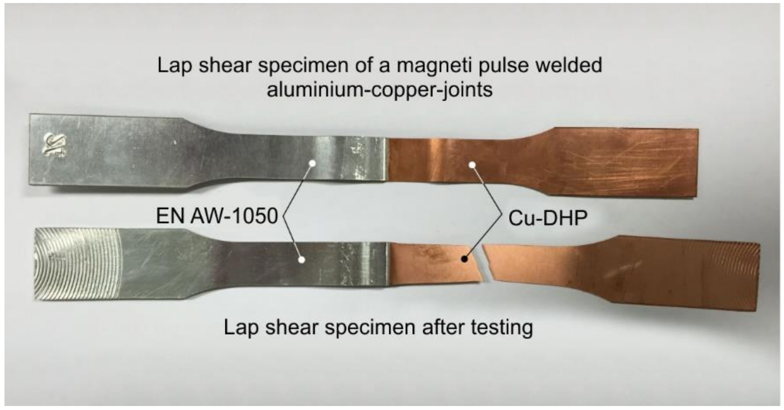

Figure 4 Lap shear test of magnetic pulse welded copper aluminium hybrid sheets

For a more detailed characterisation the joint zone was analysed microscopically. Figure 5 shows a detail from the magnetic pulse welded connection. A wavy shape with vortexes in the region of the wave peak can be clearly recognised. Similar to explosive cladding also magnetic pulse welded connections are frequently but not necessarily characterised by such a wavy weld seam. However, safety issues are significantly lower in case of magnetic pulse welding and in contrast to explosive welding the process can be easily integrated in an industrial manufacturing environment. The very small intermetallic phases, which have been detected in some magnetic pulse welded joints occur very locally and preferably in the region of the vortexes. Thus, they do not form a complete barrier layer.

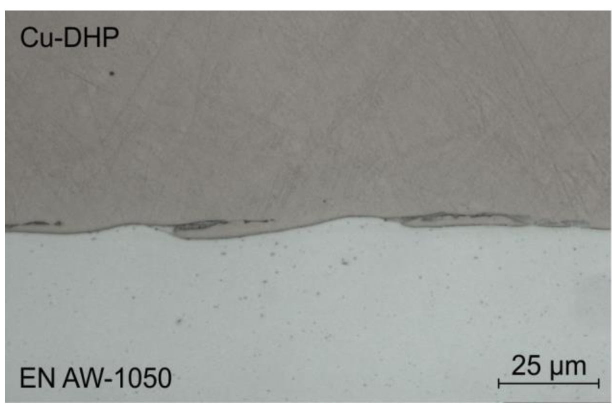

Figure 5 Cross section of a magnetic pulse welded joint

Also regarding electrical conductivity, magnetic pulse welded joints excel due to good properties. Figure 6 shows their electrical resistance in comparison to sheets, which were clamped with a defined contact pressure in a fixture. The semi-finished parts are an aluminium sheet (EN AW-1050) with a thickness of two millimetres and a copper sheet (Cu DHP) with a thickness of 1.5 mm. In the tests the voltage drop resulting from a defined imposed current was measured and the resistance was calculated via Ohm's law.

For the clamped sheets it is shown that especially for small overlaps, which are often desirable due to aspects of material, cost, and weight savings, high contact pressure is necessary in order to achieve a small resistance of the joint. For larger overlap, less contact pressure is required, but it has to be considered that this contact pressure requires much higher forces. The investigated magnetic pulse welded joints all show very small electrical resistances of the joint for the same semi-finished parts, which are hardly achievable by clamping of the sheets.

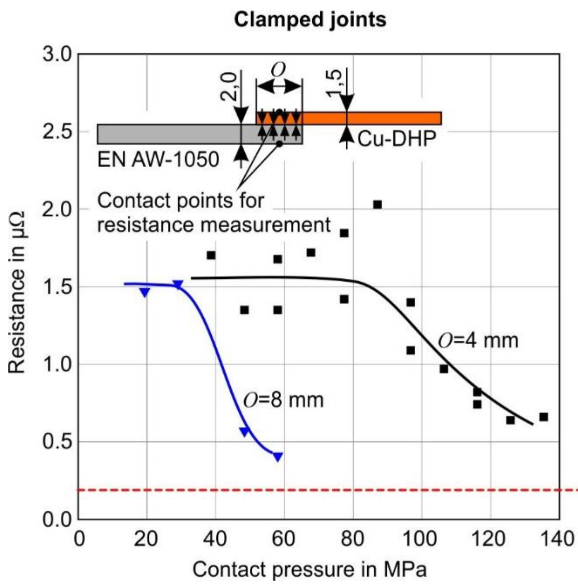

Figure 6 Electrical resistances of clamped (left) and magnetic pulse welded (right) aluminium copper joints

In addition to the copper aluminium connections, which are in the focus here, numerous other multi-material connections are feasible by magnetic pulse welding. However, at least one joining partner (the flyer) should feature high electrical conductivity in order to allow high efficiency of the process. Among the feasible multi-material connections are e.g. steel-aluminium joints [8], which are especially interesting for the automotive industry, as well as aluminium-titanium connections [9]. Together with Volkswagen AG the Fraunhofer IWU has shown that even joints of aluminium and metal-plastic hybrid sheets as the material LITECORE developed by Thyssen-Krupp can be magnetic pulse welded (see Figure 7).

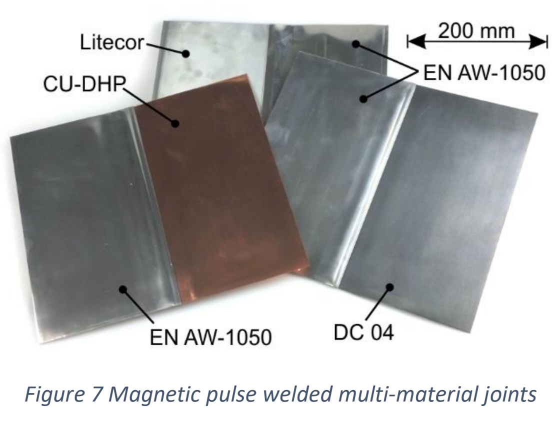

Figure 7 Magnetic pulse welded multi-material joints

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