Ultrasonic Metal Welding (USMW): Sonotrode and Copper plate

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Single-sided Resistance Element Welding (SREW) for joining of steel and non-ferrous materials

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The Single-sided Resistance Element Welding (SREW) is a further development of resistance element welding in which hybrid joints between steel and non-ferrous materials, especially aluminium, are joined by welding using rivet-like elements (auxiliary joining parts). With the SREW, this can be realised with only one-sided component accessibility. In a first manufacturing step, the elements (steel) are stamped into the cover layer, consisting of a non-ferrous material, and the finished semi-finished product is joined to a base layer (steel) in a second step by resistance welding. The joint is formed between the auxiliary joining part and the base layer. The connections produced in this way are both materially (welding lens) and positively (element) bonded. The challenges of SREW without a mating layer were investigated in detail at ISF as part of a cooperative project (LWF, Paderborn) and appropriate measures were developed to improve the quality of the joints.

With SREW, a distinction can be made between the process variants shown in Fig. 1. Both connections with one element (butt-spot method, ground electrode contacts base plate) and connections with two elements (double-spot method) can be realised for each resistance weld.

![Butt Spot Process Diagram](image1)

**Fig. 1: Process variants of the SREW for joining one element (butt spot process) or two elements (double spot process) per weld in steel-intensive mixed constructions**

In addition to the design of the auxiliary joining part (material, projection geometry, etc.), the challenges of SREW without a backing layer lie particularly in the stiffness of the structural component serving as the base layer and in the shunt problem. The high electrode forces usually required for the joining task lead to deflection of the base layer if its stiffness is insufficient, which in extreme cases can lead to local plastic deformation of the component. This is connected with the high demands on the repositioning behaviour of the system technology used in this process. If the electrodes are not repositioned quickly enough, the result is a non-constant force behaviour, which leads to a reduced welding quality with pronounced weld spatter formation.

The cross connection problem occurs in particular with highly conductive cover layer materials (e.g. aluminium materials) and requires additional measures for the insulation of the resistance elements used. Insufficient insulation of the elements leads to a partial to complete current flow via the cover layer, which impairs or prevents the formation of a welding lens. The approach pursued here was to reduce the shunt current by a high-resistance coating of the element with a lamellar layer system (immersion bath, bulk material, Zn/Al lamellae). Fig. 2 shows an example of a connection successfully created by SREW with weld line formation between element and steel base layer.

![Double Spot Process Diagram](image2)

**Fig. 2: Macro section of an SREW joint with aluminium cover layer; weld lens formation between steel base layer and element projection**

The SREW represents a cost-effective variant for the production of joints from steel materials in combination with a non-ferrous composite partner. The flexibility of the welding unit (spot welding, REW and single-sided REW joints), but also the low-cost auxiliary joining parts and the possibility of combining with adhesives (hybrid joining) stand out, so that the SREW is economically competitive with rival processes such as bolt setting and flow punch bolting.

The presented investigations were carried out within the framework of the IGF research project “Single-sided resistance element welding for steel-intensive mixed construction” (IGF project no.: 20560 N) at RWTH Aachen University and funded by the Federal Ministry of Economics and Climate Protection (BMWK) on the basis of a resolution of the German Bundestag.
Predictive Quality Monitoring in Ultrasonic Metal Welding

Florian W. Müller

As part of a ZIM project, a process monitoring system for metal ultrasonic welding was developed at ISF together with ENLYZE GmbH. For the first time, this system does not require sensors in the welding area and can therefore be flexibly integrated into existing industrial production processes. The primary data source for assessing the joint quality are current and voltage signals, which are measured directly in the generator of the welding system. After pre-processing, the measurement data is transferred to a cloud using an edge device and evaluated there.

Ultrasonic Metal Welding (USMW) is an industrially established welding process for the production of battery cells, power electronics and wiring systems. Copper and aluminium components are primarily joined. Due to the short duration of the process and the poor observability of the joint formation, the process represents a black box; the exact interactions of the numerous influencing variables (e.g. surface cleanliness, material hardness, part geometry) with each other and with the joint quality have so far only been described for very specific welding configurations and in the laboratory environment. This makes it all the more important to monitor the joint quality achieved during ongoing production. Solutions integrated into the welding machine control for process monitoring based on the individual statistical variables of welding time and penetration distance (in an energy-controlled process) are proven to be only suitable to a limited extent for adequately reflecting the variables influencing the welding process and the joint quality.

At ISF, the potential of external sensors for monitoring welding tool vibrations and predicting joint quality has already been demonstrated in previous projects. Here, characteristic values are derived from high-frequency position signals (laser triangulation sensor, eddy current sensor) or speed signals (laser doppler vibrometer measurements) after suitable filter operations. These can be correlated with quality data of the weld by means of machine learning, e.g. in the form of a so-called Random Forrest Algorithm or a Gaussian Process Regression. These models can be used to predict the welding quality. This process monitoring requires the accessibility of the welding tools (sonotrode and anvil) for suitable measurement technology, vibrations with amplitudes in the order of 1 µm to 25 µm with sampling rates >100 kHz have to be recorded.

Together with ENLYZE GmbH, a sensor system has now been implemented between the generator and transducer within an USMW machine. The electrical power measurements recorded at this position with a very high sampling rate are uploaded to the company's own cloud for each weld via an edge device from ENLYZE GmbH. Fig. 1 depicts a schematic of the system used. In the cloud, the recorded power data is automatically linked with the specific used welding parameters and additional sensor data, and the signals are then processed further. In the training case, the link is also made with individual quality information in the form of joint strengths determined by destructive testing methods.

In later industrial applications, it is planned to carry out the entire data pre-processing and, if desired, also the quality prediction on the edge device at the welding machine. It is already possible to connect the device to existing machine controls (e.g. PLC) and databases (ERP/MES systems) for data aggregation, evaluation and forwarding.

Parallel to the development of a prediction algorithm based on the electrical power signals, the ISF is linking the high-frequency recorded power signal, the low-frequency power signal of the system control itself and the already known external measurement equipment for vibration monitoring. In this way, the loss of information between the mechanical vibrations of the welding tools and the electrical signals of the generator can be described.

Based on the findings obtained, investigations into the process control of the USMW will be carried out at the ISF in the future.

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This Project is supported by the Federal Ministry for Economic Affairs and Climate Action (BMWK) on the basis of a decision by the German Bundestag.
ISF Intern
Mr. Mirco Olesch has been supporting the arc welding team as a research assistant since January 2022.

We congratulate Kathrin Heldmaier and Lukas Oster on the birth of their son Emil, and Darja Wentnagel and Josef Weiland on the birth of their son Marten.

Dr. Marek Simon, Lars Kunert, Dr. Oliver Engels, Aleksej Senger and Rebecca Bauer left the Institute in the last six months. We wish them all the best for their future career.

Promotions
Dr. -Ing. Erick Gonzalez Olivares received his doctorate on 29.11.2021 with the topic "Hybridisation between plasma and MSG processes in a tandem configuration for aluminium joints".

Dr. -Ing. Sebastian Stüßer-Ufer successfully completed his doctorate with the oral examination on 23 February 2022 on the topic of "Model-based determination of beam characteristics in electron beam welding and their effect on the process result".

Doctoral Anniversaries
The institute congratulates the “Golden” doctoral anniversaries who successfully completed their doctorate at the ISF in 1972 with the oral examination: Dr.-Ing. Jörg Haschke, Dr.-Ing. Alfred Kuns-mann, Dr.-Ing. Arnold Engel, Dr.-Ing. Günter Wichelhaus, Dr.-Ing. Ortwin Hahn and Dr.-Ing. Abdul R. Shaheeb.

We congratulate Dr.-Ing. Mathias Dobner, Dr.-Ing. Rainer Miebach, Dr.-Ing. Sabine Roosen, Dr.-Ing. Sven Hicken and Dr.-Ing. Oliver Kropla on their “Silver” doctoral anniversary, with examination held in 1997.

Concluded Research Projects
Investigation of the influence of non-stationary processes in the plasma-arc on the penetration depth in high-frequency TIG welding (DFG RE2755/51-1)
Strength assessment of high-strength welded joints using transverse tensile tests (IGF-Nr.: 20.439 N / DVS Nr. 01.3062)
Extension of the process monitoring of electron beam welding by optimising the in-process sensor technology (IGF-Nr.: 20.502N / DVS Nr. 06.3065)
Fully mechanised adaptive root welding on wind energy foundation structures (IGF-Nr.: 00.050 EWN / DVS Nr. WE.3128)
Analysis of the time constants of EB capillaries by self-illuminating x-rays "x-ray EB capillary" (Dobeneck Stiftung)

RWTH Innovation Sprint: WAAM Control Platform
System identification and monitoring of ultrasonic metal welding processes "SIMUSS" (IGF-Nr.: 20.161N / DVS Nr. 05.080)

New Research Projects
Influence of the metal vapour on the beam properties and the capillary during laser beam welding by investigations at ambient pressure and vacuum (DFG RE 2755/72-1)
Development of practice-oriented methods for 3D printing of the composite material reinforced concrete (BMI / BBSER – Zukunft Bau)
Demonstration of an energy-optimised process control for ultrasonic metal welding based on process parameters "DEGU" (DFG RE 2755/75-1)
Simulative prediction of the manufacturing process in additive gas metal arc welding (DFG SFB 1120 TP T03)

Historical
Welding technology course has a long tradition in Aachen. The first lecture on “Welding Technology” was given by Dr. –Ing. Max Fink in the winter semester of 1932/1933. This was subsequently supplemented by a series of practical exercises, e.g. on gas welding and electric arc welding, and offered twice a year. In 1938, the series was taken over by the lecturer Dr.-Ing. Hunsicker and offered until the closure of the university in 1944/1945. It started again in the summer semester of 1947. Prof. Dr.-Ing. Krekel held the lecture “Welding Fabrication Processes” as an associate professor at the still vacant chair of “Construction and Strength”.

In 1949/1950 staff and course catalogue of the Rheinisch Westfälische Technische Hochschule Aachen, how it is now called, and this lecture was still offered and read by Prof. Krekel. However, now for the first time under the roof of the vacant chair of “Welding Technology” for which Prof. Krekel taught as an associate professor. The Chair of Welding Technology, whose direct successor the Institute of Welding and Joining Technology sees itself as, will therefore celebrate its “75th” anniversary in 2024. We ask all alumni and friends to please take note of the anniversary.

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