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BRITE/EURAM Project BE-3037: Plasma and Laser Enhanced Arc Welding for Automatic Application

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A. Objectives of the project

The Overall objective of this focussed fundamental research project is to develop a fundamental understanding of the mechanisms by which the plasma and laser assisted arc processes are governed in order to improve Performance, reduce defect levels and increase productivity. The primary scientific aims of this project are as follows:

- Physical mechanisms of the welding arc.
  - Investigation of the energy distribution in the arc.
  - Investigation of the energy transfer to the weldpool for both partial Penetration and keyhole geometries.
  - Determination of the role of radiation on arc structure and energy transfer efficiency.
  - Development of mathematical models as a basis for improved process understanding and technological optimization.
- Determination of the operating Parameters for positional plasma keyhole welding.
- Enhancement of the arc by a low power laser beam.
  - Examination of the influence of laser beam enhancement on arc stability, weld quality and productivity.
  - Improvement of arc stability, ignition behaviour and reliability by laser enhancement.
  - Determination of the operating Parameters for positional laser enhanced arc welding.
  - Development and construction of a combined laser-arc welding facility, using a laser of comparable low power (< 300 W).

The Programme will examine the non-consumable plasma and laser enhanced TIG welding process for automated application. Work will include an investigation of the influence of metal vapour composition on arc stability and energy transfer. Experiments will also include an examination of joining dissimilar materials and the identification of operational limitations (weld pool and process stability) for welds made at high welding speeds.

This fundamental research project is focussed on delivering a basis for the future industrial implementation of laser enhanced arc and optimized plasma welding. It should proof the possible industrial benefits of these processes.

B. Identification and role of the partners

Institut für Schweißtechnik (IfS), TU-Braunschweig, Germany [Coordinator]

The IfS is responsible for the combination of arc and focussed laser beam, detailed analysis of the welds and several measurements to determine the structure of the arc. For these purposes laser Systems, arc sources and a fully equipped metallographic laboratory is available.

Institut für Theoretische Physik (ITP), TU-Braunschweig, Germany

The responsibility of the ITP includes modelling of the processes occuring close to the surfaces of the electrode and the workpiece. They are the transfer of energy from the arc to the workpiece, the erosion of the electrode and the electron emission behaviour of the workpiece and the electrode, which accounts for significant effects in the arc-plasma. In addition to that, the interaction of the supporting laser with the workpiece is studied paying special respect to evaporation, which leads to strong changes in the ignition and stability behaviour of the arc-plasma. Besides physical modelling, Computer Simulation methods are developed at the ITP to allow Computer experiments to be carried out.

Cranfield Institute of Technology (CIT), United Kingdom

Cranfield is responsible for aspects of the Programme involving the constricted plasma arc process. The temperature distribution of the arc is extensively studied in conjunction with the experimental and theoretical developments of the other Partners. Parameters are developed for positional plasma keyhole welds. Modified arc properties are examined in order to assess the suitability of the process for high speed welding.

University of Essex, United Kingdom

The contribution of Essex is from the departments of Physics and Mathematics. Essex is jointly responsible for theoretical developments and modelling of arc and weld pool behaviour with the ITP of the TU-Braunschweig. Responsibilities include the development of the basic *arc* model, the examination of radiative transfer behaviour and the modelling of the weld pool flow patterns for keyhole welding geometries. Results will be correlated with experimental input from the CIT and the IfS for comparison and model refinement .

C. Motivation for the project

In production industry the beam technologies (Laser or Elektron-Beam) for joining and surface treating are often too much capital intensive. Therefore the largest amount of work is done by conventional arc welding.
This project will show the optimization potential of the conventional high quality arc welding process TIG and Plasma. For higher productivity, quality and process reliability a deep understanding of the underlying physical mechanisms is definitively needed. From the physical point of view, the aim is to concentrate the source of energy for welding (i.e. the arc). Two arc welding processes offer significant potential for such optimisations:

1. The concentration of arc energy by convection (called constricted or plasma process) – applicable for thicker materials

2. The laser induced focussing of the Tungsten Inert Gas Arc (TIG, GTAW) – applicable for thinner materials

Both methods are suitable to control the arc plasma and achieve therefore a higher process stability as well as an increased welding-depth and -speed.
These processes are compared critically and by the method of constructive competition they are to be optimized with respect to cost, quality and productivity. The application area can be found in automated high speed welding of stainless steels and aluminium even in complex geometries.

D. Methodology to reach the project goals

The approach of the project is to develop new or enhanced arc welding methods by starting from the basic understanding of the underlying physical processes and therefore to deliver fundamental research results suitable for industrial process development. The main methods used are:

- Arc diagnostics and mathematical modelling
- Setup of experimental procedures for laser enhanced TIG welding.
- Welding trials, Parameter optimizations and analysis of the welds.

By means of exchange of staff, research students, experimental equipment as well as Computer programs and data an Optimum information flow and a maximum use of capacity of the experimental equipment is sought

E. Results of the research to date

The first results of the research can be found in the last BE-Workshop paper [1]. The results of the modelling efforts are presented in a number of papers and can also be found on the projects poster presentation. In the following subsections some results of the arc diagnostic experiments and the welding experiments will be shown.

E.1 Arc diagnostics

For the application relevant optimization of the plasma and TIG welding process two tools are of major importance:

- Low-tost and easy to use diagnostic methods and
- Comprehensive mathematical modells

Both are related together, because modehing of a complex physical system like the welding arc is impossible without experimental data, and simple

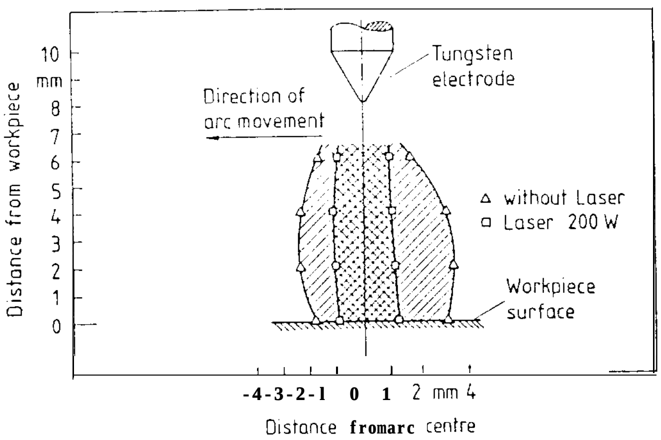

Figure 1: **Main current channel of a TIG and a Laser enhanced TIG arc**

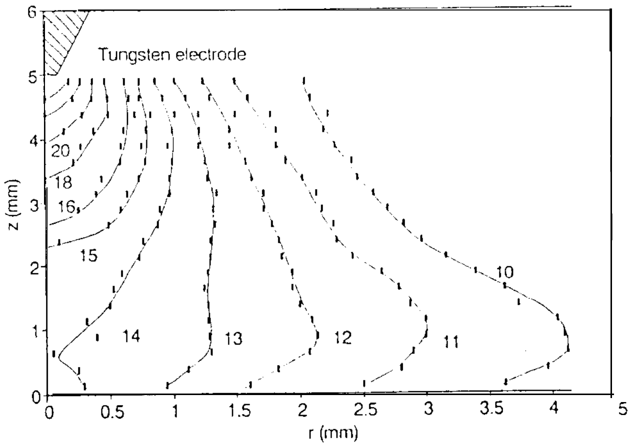

Figure 3: Temperature **map of a 100A,5mm TIG arc**

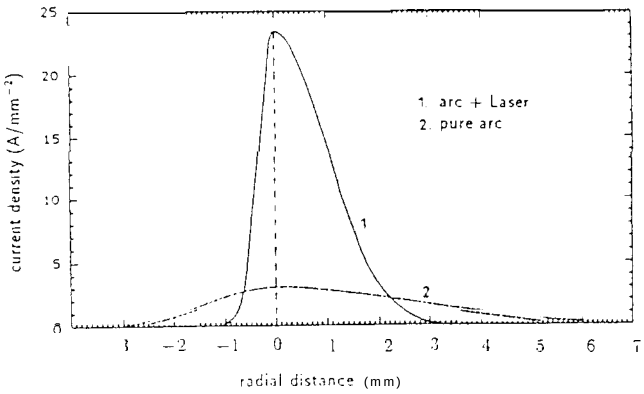

Figure 2: **Current density at the workpiece for a TIG and a Laser enhanced TIG arc**

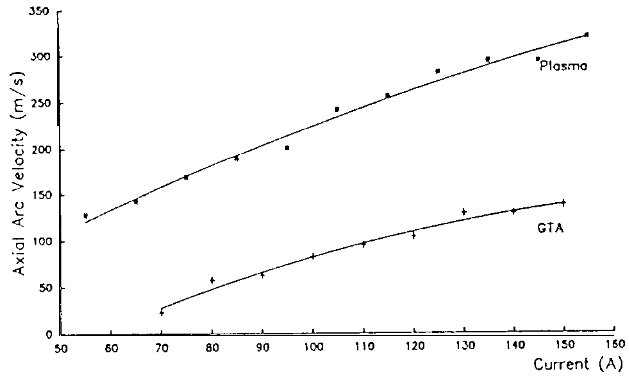

Figure 4: **Comparison of TIG and Plasma arc velocities**

diagnostic methods often need a model to compute the physical from the measurement data.

The simple diagnostic techniques used are high speed probe (figure 1) and split anode (figure 2). These measurements are showing the effect of laser enhancement:

- The electric current channel of the arc is pinched.
- The current density of the arc at the workpiece surface (and therefore its energy density) is increased by a factor of 2 to 5.

These techniques can be used to optimize the torch and welding Parameters. For getting physical information out of this measurements, a further development is needed, because these well known techniques [4,5] are not taking account of the movement of the arc over the workpiece – an effect becomming even more important for high welding Speeds.

For understanding the process and modelling purposes more fundamental physical Parameters are needed. The arc temperature map was measured by emission spectroscopy (figure 3) and arc pressure measurements show the principai differences between plasma and TIG on a quantitative scale (figure 4).

E.2 Welding experiments

The most impressive actual result of the project is the following fact:

- The productivity and quality of laser enhanced TIG welding is prooved to be more than 150% that of ordinary TIG.

From table 1 the 71% increase of welding speed can be seen. But laser enhancement offers not only twice the speed, is offers also much better joint quality than conventional TIG.

At the end of the project, the first combined welding heads for laser enhanced arc welding are available together with Parameter sets for typical applications:

Welding Parameter	TIG	Laser-TIG
max. distance for HF ignition mm	2.5	8
max. arc length for welding[mm]	6	16
typical welding speed (130A TIG) [mm/min]	380	650
seam depth to width ratio	0.4	1
typical heat input per length [kJ/m]	320	160

Table 1: **Comparison of typical Parameters for conventional- and laser-enhanced- TIG welding of 2mm stainless steel**

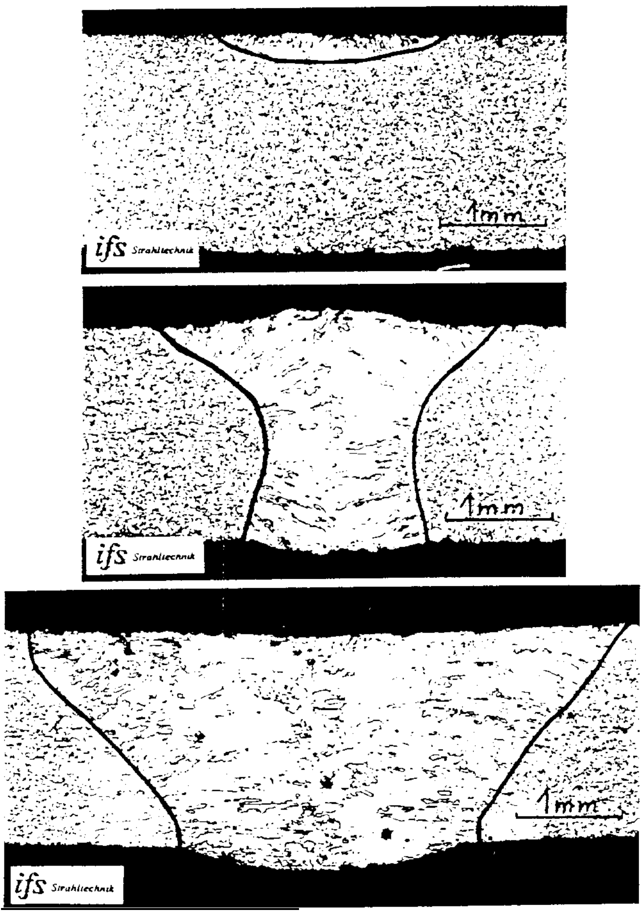

Figure 5: Cross sections of a typical Laser-TIG weld and a TIG weld (Parameters as in table 1; top: conv. TIG at 650 mm/min, center: Laser-TIG at 650 mm/min, bottom: TIG at 380 mm/min)

- High speed welding of stainless steel (0.5-3mm) even in complex joint geometries.
- DC-EN high speed welding of aluminium.

F. Technical and administrative difficulties of any kind encouraged during the life of the project

F.l Administrative difficulties:

- Due to the responsibility of the commission the project started 3 months to late and the real starting date became known one week before the project started.
  Therefore the experts intended to be recruited for the project changed to industry and new suitable staff could not be found in time. This problem led to a significant delay in the work and some tasks have to be rearranged. By intensive efforts of all partners the problems will be overcome at the end of the project.
- Because all partners are universities with extensive adminstration by their own the delay of up to 6 months in the periodic payments of the commission has wasted approximately 1 man-month for administration.

Nevertheless, the general rules of the contract seem to be well suited and all partners would like to thank the Commission's scientific officer for his support.

F.2 Technical difficulties:

Beneath some minor technical difficulties easily solved, the main technical problem of the project is the initial underestimation of the experimental setup for laser enhanced arc welding. Because this is a fairly new process the experiments had to be changed several times in order to include the actual knowledge of the process into the setup and making further developments possible.

Literature

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[2] Wendelstorf, J. et al: Laserinduziertes Fokussieren des WIG Lichtbogens, Große Schweißtechnische Tagung Friedrichshafen 1992

[3] Finke, B.R.; F. Stern and 1. Decker : Auswirkungen eines unterstützenden Laserstrahls auf den WIG-Schweißprozeß, DVS-Berichte, Vol. 135, p. 149-152, DVS-Verlag GmbH, Düsseldorf, 1991

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