Plasma arc welding (PAW) is a modern welding technique for challenging joining tasks in a wide range of materials and plate thicknesses. A further improvement of the welding characteristics involving achievable welding speed, process stability and penetration depth is expected by an additional low energy laser beam with a maximum output power of 600 W. The paper presents an experimental and numerical analysis of the interaction between a plasma arc and a superimposed laser beam. The experiments are carried out with a non-concentric set-up of the plasma arc column and the laser beam. As results of bead-on-plate welding trials the cross-sectional weld areas were presented in order to demonstrate benefits of the combined process in comparison to separately conducted arc and laser welding. Furthermore, high speed video images (1 kHz frame rate) with synchronized current and voltage recording (1 MHz frame rate) were used. The experimental results demonstrate a different behaviour for welding steel and aluminium. In case of welding aluminium, an arc guidance was observed whereas destabilization effects occur for welding ferrous alloys. A numerical magneto hydro dynamical (MHD) arc model with a concentric set-up of arc column and laser beam set-up was aimed to improve our understanding of relevant interaction phenomena between the plasma arc and the laser beam.

**IIW-Thesaurus keywords:** Argon; Electric arcs; Lasers; Laser beams; Plasma; Plasma welding; Simulating.
Experimental set-up

The experiments were done using a non-concentric configuration of the plasma torch and the laser beam, which are both inclined with respect to the surface of the metal sheet being welded, see Figure 1. An Yb-fibre laser (IPG) was used with a laser wavelength of 1,070 nm and a minimum focus radius of 20 μm. The applied plasma arc system consists of a water-cooled plasma torch (ABIPLAS WELD 150) and a constant current power source (EWM Tetrix 400) using DC-EN-polarity. The parameters being constant during the experiments are the electric current of 100 A, the plasma gas flow rate of 0.8 l/min argon and the bore diameter of 2.6 mm in the plasma nozzle. Figure 1 shows the experimental set-up used.

A high-speed video camera with a resolution of 1k by 1k pixel and 1,000 frames per second (fps) was used for a visual process observation. Simultaneously, the synchronized values of the electric current and the arc voltage were recorded with sampling rate of 1 MHz. The camera was positioned perpendicular to the welding direction. Suitable narrow band pass filters were used in order to improve the observation of the arc root at the workpiece.

Experimental results

The interaction of the arc and the laser beam was investigated for bead-on-plate welding of aluminium alloys and steels. A significant influence of the laser on the arc behaviour was mainly observed for aluminium plates, Figure 2. Without laser beam action, two arc roots and attachments are established as a result of the inclined arrangement of the plasma torch. One arc root and attachment is on axis with the plasma torch (a). The second one is transient and specifies the arc root of the lowest electric resistance (b). It was observed that both arc roots compete to each other and thus no continuous welding seam was produced.

However, after switching the laser on, the arc attachment is fixed at the laser-generated hot spot (c) and the arc column is stabilized.

The top of Figure 2 shows the ability to track the plasma arc attachment at an aluminium workpiece by a laser of 400 W. The involved interactions between the laser beam and the arc plasma decrease the arc voltage. The reduction is a nearly linear function of the applied laser power. It is about 3 V for a laser beam power of \( P_L = 600 \text{ W} \), see Figure 3.

Besides the arc root stabilization it was possible to move the arc attachment sidewards, forwards and backwards up to 2 mm, which is about half of the free arc length. Therefore the arc attachment at aluminium can be favourably controlled by a laser beam.

Figure 4 shows cross-sections in AlSi1MgMn sheets which were produced by plasma arc or laser only and by plasma arc and laser. The combination of both energy sources causes the increase of weld seam section from 2.2 mm\(^2\) (plasma arc only) or 1.8 mm\(^2\) (laser beam only) up to 6 mm\(^2\). The depth and the width of the weld seam increase by defocusing of the laser spot. The largest weld seam sections were found for a focus position displacement \( \Delta z \) of 7 mm above the workpiece. Consequently, the highest degree of melting efficiency was not found for the highest focal laser beam intensity.