Introduction

Plasma arc welding provides the productive and high performance joining of iron, titanium and aluminium. For an increase of the welding speed, the weld penetration and the stability of the process the plasma arc can be supported by laser radiation. In general, disadvantages of the single joining processes can be compensated by such a combined technique. However, the most of published scientific work concerning such hybrid joining technologies was aimed to high power laser processes of several kW and their advancement by welding arcs [1]. In these cases, the arc undertakes only an assisting function compensating some characteristic drawbacks of laser beam welding processes.

The combination of a welding arc with a low power ($P \leq 600$ W) laser provides the approach to influence mainly the arc column or the arc attachment by coupling the laser energy directly with the process region. Research results of Steen [2] or Cui and Decker [3-5] have already demonstrated that a laser beam of some hundred Watt to 2 kW is capable of stabilizing a TIG arc. They demonstrated an increased heat flux density due to a focussed arc attachment and a decreased arc voltage drop. Steen [2] traces back these effects to a locally increased number of free charge carriers at the anode surface. Otherwise, it was shown for a 0.2 mm-thick titanium sheet that an arc stabilization happened, even if the laser beam and the arc were positioned at the opposite sides of a workpiece. Cui and Decker [3-5] point out the influence of metal vapour, which results from the laser-induced evaporations of base material. They assume a local increase of the electric conductivity of the plasma. Albright et al. [6] demonstrate low power laser arc assistance due to a provided pre-ionisation of an arc root. Recent works of Hermsdorf et al. [7, 8] underline the role of the optogalvanic effect which is present in the arc column and, in particular, at the cathodic workpiece in gas metal arc welding (GMAW).

The present paper is focussed on investigations of a welding process with a combined heat source consisting of a plasma arc and a laser beam with a maximum output of 600 W. The work is aimed to characterize the interaction between the arc column and the laser beam and to comment the involved physical effects. In contrast to TIG arcs, which have been already investigated intensively, the plasma arc is characterized by significantly increased plasma flow velocities and energy densities in the arc column [9, 10]. Both provoke a high stability of the arc column. A fibre laser was used as the laser beam source, which permits a nearly diffraction-limited beam quality. This enables high energy densities at the workpiece. The interactions were studied for welding mild and stainless steels and aluminium alloys as well. The work is based on experimental investigations and numerical MHD-simulations.

Abstract

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 1070 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 1000 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 $P_L = 600$ W, see Figure 3.

Besides the arc root stabilization it was possible to move the arc attachment sideways, 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 mm² (plasma arc only) or 1.8 mm² (laser beam only) up to 6 mm². 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.