Nutzung elektromagnetischer Volumenkräfte beim Laserstrahlschweißen

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Extended Abstract

Laser beam welding of aluminium alloys receives more and more an increasing acceptance in industrial manufacturing due to the specific advantages of the joining procedure in combination with aluminium lightweight construction. Therefore, the efficiency of the procedure and the quality of the process become main points.

On the other hand, the highly dynamic welding process as a consequence of low viscosity of the melt, high heat conductivity, and resulting large volume of the weld pool lead to process instabilities and typical seam defects like pores, blow holes and ejects. Responsible for these negative effects is a fluctuating capillary which were subject of numerous investigations in the past. To avoid or to reduce these problems, great efforts were taken to find suitable process and laser parameters as well as using skillful modifications of the energy coupling. Examples are the double focus technique, laser hybrid techniques, and a time dependent energy transfer by a modulated laser beam.

This paper presents the results of a new approach: instead of achieving the required effects by modification of the energy coupling with the aid of double focus technique or an additional heat source, the weld-pool geometry will directly be modified by using electromagnetic volume forces. Numerous welds with full and partial penetration using both CO_2 and Nd:YAG lasers demonstrate that this method directly influences the seam geometry and top-bead topography as well as the penetration depth and the evolution of pores and cracks. The precondition to produce electromagnetic volume forces is the existence of a current density in the weld pool interacting with a magnetic flux density. Both the current density and the magnetic field can be generated in different ways.

Based on the origin of the electromagnetic body forces a total of four electromagnetic concepts can be classified. According to these concepts a basic characterization and estimation of dimensionless numbers and technical realizable Lorentz forces in the weld pool will give a first sense of possible effects and effectiveness of every single concept, which will be verified in basic experimental investigations. In consequence of the first estimations only three of the introduced electromagnetic concepts seem to become a technical meaning, because the flux induced concept produces only marginal Lorentz forces compared with the others, but nevertheless its contribution is latent

existing. The precondition for all other electromagnetic concepts looks very promising in order to affect the welding process in its own and specific way.

The ***"intrinsic" concept*** which is based on the existence of an "intrinsic" current in the weld pool, requires only an external magnetic field perpendicular to the welding direction, which causes a drastical change in the shape of cross-sectional behavior (tapered or u-shaped), depending on the orientation of the magnetic field during CO_2-lasers beam welding. The increasing of the cross sectional area can be explained by altering the melt flow underneath the capillary which is driven by the effective electromagnetic forces. Furthermore, a "stabilizing effect" was found by the electromagnetic forces since the area of the seam cross-section does not vary so much statistically as it does without the acting volume forces. Furthermore above a threshold value of approx. 0,3 T the shape and cross section area are independent of the magnitude of the magnetic field. In contrast to the achieved effects with CO_2-lasers, with Nd:YAG-lasers no significant effect could be observed, neither in full nor in partial penetration welding. Obviously this is caused by a minor or absent „intrinsic current" in the case of Nd:YAG welding.

Using the ***"conductive scheme"*** where both the electric current and the magnetic field have to be applied externally in various manners, the weld pool can be strongly influenced. In the case of full penetration welding, it is possible to „lift" or to „lower" the weld pool independent from the laser wavelength and in accordance to the right hand rule. The method, therefore, can be used to shape the geometry and to enhance the quality of the weld seam.

In further investigations, the effect of electromagnetic body forces resulting from the interaction of an external current and its self-induced magnetic field was studied. Hereby, the current was fed into the workpiece via a tungsten electrode or a filler wire. The resulting phenomena are the same independent from wavelength and means of current feed and leads to an increasing of the welding depth.

A special mock-up experiment containing a characteristic laser weld pool in the scale of 15:1 which is filled with liquid InGaSn was used to visualize the weld pool dynamics driven by self induced Lorenz forces. With the help of some tracer particle a vortex flow could be observed by applying 600 A to the electrode. Independent of the polarity the vortex flow has always the same sense of direction and acts downwards in the front field of the weld pool. Therefore, this effect can obviously be used for "stirring and mixing", e.g. to get homogeneous element distribution.

The most promising concept is the "***inductive scheme***" which represents a contact-less way to generate volume forces in the weld pool. A fast oscillating magnetic field induces eddy currents in the metal and generates always volume forces in the weld pool that act like a pressure onto the melt surface. To demonstrate the workability of this electromagnetic system, an aluminium box filled with liquid solder (SnPb) was shown to be prevented from leakage during full penetration welding in vertical down direction. Up to a hydrostatic pressure of 0,02 bar the electromagnetic pressure were able to prevent the leakage of the solder.

The use of electromagnetic body forces during laser beam welding will be demonstrated by means of two examples. The first one is a convincing method to reduce process pores by using an conductive scheme to generate Lorentz forces "downwards" which act similar to an additional pressure in the melt. Acting like an Archimedic force with a negative pressure gradient towards the melt surface, they enhance the degassing of the weld pool. The additional magnetic pressure seems to influence the capillary behavior in a positive kind and reduces pore formation as well. The second example is an impressive geometry shaping method to avoid seam sagging either with the help of conductive- or inductive scheme. Depending on the magnitude of the generated effective Lorentz forces in the weld pool, the seam can be shifted infinitely. With the help of the inductive electromagnetic support system the gravitational process limitation (gravity drop out) during welding of 18 mm thick stainless steel without using backing plates could be avoided.

During all these investigations the vital question about the origin of the ***„intrinsic current“*** in laser beam welding remained unanswered. The process-inherent phenomenon which depends on the laser wavelength could be ascribed to the laser induced plasma based on experimental investigations and described by theoretical plasma estimations. Fact is that an intrinsic current could be measured during CO_2-welding as well as in Nd:YAG-welding. But only in the case of welding with 10,6 µm wavelength the generated intrinsic current is sufficient high enough to show the above mentioned effects by interacting with an applied magnetic field. It turned out that the temperature difference caused by plasma-wall-contacts is responsible for this process inherent current in the weld pool.

In total, the magnetic assisted laser beam welding with its various possibilities of applying and generating Lorentz forces is a successful, industrially usable means for influencing the weld pool directly.