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High power laser beam welding of thick-walled ferromagnetic steels with electromagnetic weld pool support

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Abstract

The development of modern high power laser systems allows single pass welding of thick-walled components with minimal distortion. Besides the high demands on the joint preparation, the hydrostatic pressure in the melt pool increases with higher plate thicknesses. Reaching or exceeding the Laplace pressure, drop-out or melt sagging are caused.
A contactless electromagnetic weld support system was used for laser beam welding of thick ferromagnetic steel plates compensating these effects. An oscillating magnetic field induces eddy currents in the weld pool which generate Lorentz forces counteracting the gravity forces. Hysteresis effects of ferromagnetic steels are considered as well as the loss of magnetization in zones exceeding the Curie temperature. These phenomena reduce the effective Lorentz forces within the weld pool. The successful compensation of the hydrostatic pressure was demonstrated on up to 20 mm thick plates of duplex and mild steel by a variation of the electromagnetic power level and the oscillation frequency.

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Keywords: laser beam welding; thick-walled steel; ferromagnetic steel; weld pool support

1. Introduction

The demand for powerful systems leads to thicker-walled dimensions due to the constructive requirements. Especially the safety of joined components has priority in welding of thick-walled components in high-risk sectors. There is a growing application of duplex steels having good properties in terms of strength and corrosion resistance

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in the pipeline and reactor construction industry, in the chemical apparatus engineering and offshore wind power plants [*Bargel and Schulze* (2008)]. Nevertheless non- and low-alloyed steels are widespread in a variety of industrial applications. Compared to conventional arc welding processes, laser beam welding offers many advantages: By developing modern high power solid-state lasers, there is the opportunity of welding thick plates in single-pass, contactless, automatically and with a concentrated energy input. This results in small heat affected zones (HAZ) and a favorable weld shape with almost parallel side walls. Regarding to the achievable welding speed and the low distortion, full penetration laser beam welding excels in comparison with regular arc welding. Apart from the high demands on the joint preparation resulting from the low tolerance of laser beams towards offset and tilting, the challenge of full penetration laser beam welding in single-pass configuration and flat (PA-) position is the rising hydrostatic pressure in the melt pool with increasing plate thickness. Illegitimate sagging or gravity drop-out of the melt are caused (see Fig. 1).

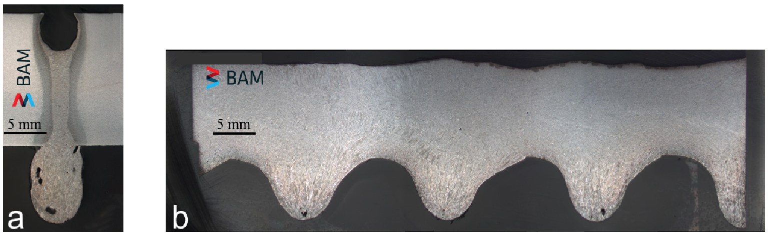

Fig. 1. Reference full penetration weld in PA position of 15 mm mild steel S235JR with IPG fiber laser using 9.2 kW laser beam power at a welding velocity of 0.5 m min^{-1}, (a) Cross-section; (b) Longitudinal section.

The hydrostatic pressure at the root side of the weld pool is calculated by:

$$p_h = \rho \, g_0 \, h \, , \tag{1}$$

where ρ, g_0 = 9,81 m s^{-2} and h are the melt density, the gravity acceleration and the plate thickness. Exceeding the surface tension, gravity drop-out occurs. The resulting Laplace pressure due to the surface tension on the root side of the weld pool is for arbitrarily curved surfaces according to *Thamsen* (2009):

$$p_\gamma = \gamma \left(\frac{1}{R_1} + \frac{1}{R_2} \right) \tag{2}$$

Under the assumption of a significantly larger radius R_2 ($R_1 = R$ und $R_2 \rightarrow \infty$) in welding direction, the equation is simplified as [according to *Avilov et al.* (2012)]:

$$p_\gamma = \frac{\gamma}{R} \, , \tag{3}$$

where γ and R are the surface tension coefficient and the curvature radius of the liquid metal drops. R depends on the contact angle α. At α = 90°, the maximum value of the Laplace pressure is reached. This means that the curvature radius is identical with the half width of the weld pool (b/2), see Fig. 2 (left). Gravity drop-out of the liquid melt can be prevented by the surface tension as long as the following condition is fulfilled [*Avilov et al.* (2012)]:

$$\frac{h\,b}{2} < l_{cap}^2 \, , \tag{4}$$