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Dual beam method for laser welding of galvanized steel: Experimentation and prospects

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ABSTRACT

Laser welding of zinc-coated steel sheets in lap configuration poses a challenging problem, because of the zinc vapours spoiling the quality of the weld. In continuation to the earlier work, the novel solution of dual laser beam method for lap welding of galvanized steel sheets is discussed here in view of the recently obtained observations and ensuing concerns. In this method the precursor beam cuts a slot, thus making an exit path for the zinc vapours, while the second beam performs the needed welding. The metallurgical analysis of the welds is encouraging showing absence of zinc in the welded area. In the current work on this technique, new experimental results have been obtained verifying the earlier observations. Along with this, the possibility of using a transversely split-up beam for the welding purposes with this approach is discussed and analyzed in this paper. This new technique is expected to be very useful in prospective industrial applications requiring higher welding throughput along with the needed quality.

1. Introduction

Welding of zinc-coated steel sheets in lap configuration poses a challenging problem to the researchers [1]. As per the results of earlier works, the solutions proposed in the last many years have not yet found an economical and easy-to-apply realization to replace conventional methods [2]. The obvious advantages offered by laser welding still justify a quest for a proper solution. The ideal solution should primarily solve the technological problem of the residual zinc vapours trapped in the welded region due to the lower boiling point of the zinc (907 °C) with respect to melting point of steel (near to the same for Fe, 1530 °C). The solution should also be practical and economical enough to be installed on the production lines [1,2].

Some researchers have studied the flaws in the produced welds of the galvanized steel in detail [3]. In order to solve this problem, researchers have tried to reduce them as much as possible through bare optimization of the welding parameters and by blowing away the residual vapours [4]. Perhaps the most obvious of the methods may well be the "prior removal of zinc coating". This method can obviously yield good results [5], but is cumbersome to implement on the floor and is thus impractical. Another possibility of welding the galvanized sheets in the edge lap configuration was presented which avoids trapping of zinc vapours in the welding keyhole but of course it comes to be unduly restrictive [1]. There have been suggestions of chemical methods including those adding some material, e.g. aluminum, on the zinc coating, but their implementation convenience is still to be established [6].

As a simpler solution, the welding process has been tried with "pulsed lasers" and it has been observed that the weld quality is improved but still the improvement is not up to the mark, i.e. some porosity has been found to be inevitable, which increases with the increase in the welding speed [3,7]. The "twin-beam method" [2,8] has been used which is of course more expensive with the use of either two sources or a split-up higher power source. But the limitations may well be encountered in its applications with different types of geometry and shape contours of the processed job. Probably a more well-known technique in this area is that of adding shims or "forced gap" between the sheets when welding in lap configuration. This method delivers impressive results [9], but at the same time, it needs time-taking pre-arrangements and may become cumbersome on the floor [2]. Anyhow such techniques have already been in use and have been patented too [10].

In view of the need of a more practical solution, the presented work is actually a further extrapolation and verification of the dual beam solution presented earlier [11,12]. In this new "dual tandem beams" method, the front beam cuts a slot in both the

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sheets with a minimal gap, thus making an exit path for the zinc vapours to-be-trapped during welding. The second beam following closely on the rear normally welds both the sheets, while joining the two edges of the slot too. This way part of the zinc may well be dispensed during the cutting process; while the residual zinc trapped between the plates conveniently evaporates during welding through the slot carved in its front, instead of spoiling the weld pool. The shielding gas flow may also help in blowing the vapour exhaust away and researchers have shown earlier how this parameter can also be optimally adjusted for different conditions [13].

In the earlier work, theoretical and mathematical treatment of this method has been presented after the general overview of the scheme. Needed width of the cut slot has been plotted against different contributing parameters. In the experimental part, the microscopic views of the outcomes of some basic experiments have been given. A basic comparison with other schemes is also presented [11,12]. As implementation, it is proposed that the Nd:YAG and CO_2 lasers can be used in tandem, with the first for cutting and the second for welding. Alternatively two beams from the same CO_2 laser source can be optically split and may also be used in tandem. The method may be viewed as an enhanced integration of the "gap-method" proposed many years ago [9] and the "twin-beam method" given few years back [2]. The given solution is described in Fig. 1. Looking at its approach, following may be the major benefits of the dual laser beam scheme presented here.

1. Dual laser beam method offers a promising practical solution for the welding of galvanized steel sheets in lap configuration.
2. The solution is easier to implement as it does not need any pre-processing or pre-arrangement with additional components.
3. In most cases, there should be no contour limitations and the welders may proceed with the jobs as per non-coated steel.
4. The solution may get rid of all the zinc vapour porosity at the lower speeds and partial of the porosity at the higher speeds.

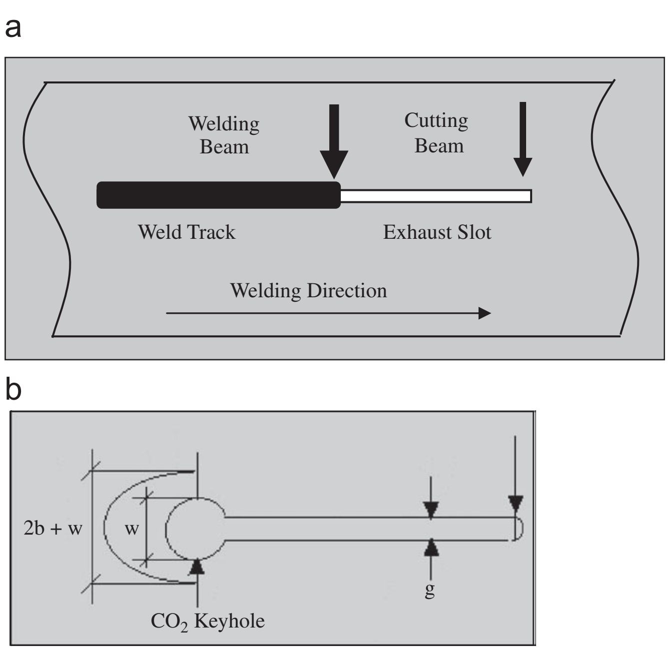

Fig. 1. Welding operation with the two beams used in tandem, (a) operation and (b) welding dimensions.

2. Theory and calculations

As per the detailed mathematical model of this technique developed earlier [11], the ferro-static head 'ΔP_{12}' on top of the weld pool generates a pressure that stops the zinc vapours from getting into the keyhole and they are alternately exhausted by the cut slot in front providing an artificial exhaust route. The exhaust velocity 'v_2' of the zinc vapours is calculated using Bernoulli's theorem, and thus

$$\Delta P_{12} = \rho_{\mathrm{Fe}} g_e t_p a, \tag{1}$$

$$v_2 = \sqrt{\frac{2\Delta P_{12}}{\rho_v}}. \tag{2}$$

Here 'ρ_{Fe}' is the iron density, 'g_e' is acceleration due to gravity, 't_p' is the thickness of the steel plate and 'a' is the wave factor or indication of non-regularity in the height of ferro-static head in the weld pool, which is normalized to 1 for simplification [9]. Vapour density 'ρ_v' is calculated using Clausius–Clapeyron equation to be $\rho_v = 21.87\,\mathrm{kg/m^3}$ [14]. The following equations express the respective flows (m^3/s) of vapours that can be exhausted through the gap, in this case the slot present in the middle of the to-be-molten area having zinc on both sides, as well as those generated by the welding action as

$$Flow_{gen} = \frac{2t_{\mathrm{Zn}} V \rho_s (w - g + 2b)}{\rho_v}, \tag{3}$$

$$Flow_{exh} = 4 v_2 t_{\mathrm{Zn}} w. \tag{4}$$

In these equations, 'b' is the width of zinc boiling isotherm whose value can be approximated for the model development, 't_{Zn}' is the thickness of the zinc layer, 'V' is the welding speed, 'ρ_s' is the solid zinc density ($7140\,\mathrm{kg/m^3}$), 'w' is the keyhole width and 'g' is the minimum gap required for the slot with the condition of $g \geqslant 2t_{\mathrm{Zn}}$. Equating both of these, we get to the needed value of minimum slot width, whose value can be given in SI system as

$$g = \frac{V\rho_s(w + 2b) - 2w\sqrt{2\rho_v \rho_{\mathrm{Fe}} g_e t_p}}{V\rho_s}, \tag{5}$$

$$g = w + 2b - 0.5145\frac{w\sqrt{t_p}}{V}. \tag{6}$$

Here we are interested in finding the optimal value of minimum gap 'g' with the condition that all the generated zinc vapours will be exhausted by the slot. The gap can be decreased further if partial zinc vapour exhaust is allowed through the molten metal and some porosity is tolerable. Value of 'b' can be approximated with two-dimensional heat flow equation. For our purposes, it may yield a value in the range '$0.5w$–w' depending on different welding parameters [15]. Any variation in this value may only shift the gap value curves a little without effecting the overall analysis.

3. Material and methods

The welding experimentation with the new technique was performed with a 2.5 kW CO_2 laser with a vertical head having a fixed beam focal length of 80 mm set at the specimen. The galvanized sheets were placed in lap configuration and were passed through cutting and welding as per given technique. The machine was operated within stable beam power ranges avoiding any unacceptable transverse beam modes. A laser diode output collinear with the main beam was used for alignment. Work-piece was placed at the focus point, which was experimentally determined using an inclined Perspex sheet in the beam path.