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Laser Operating Parameters and Their Influence on the High Speed Welding of Cr-plated Sheet Steel

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The welding of Cr-plated sheet steel at laser welding speeds in excess of 30 m/min results defects. In this work a fibre laser was used to weld Cr-plated sheet steel and the effects of the laser parameters (laser power, minimum input energy of laser input and power density) for high welding speeds (>30 m/min) was researched. The welding speed was increased linearly with the required laser power and the turning point appeared when the focus position from the focal 0 to 5 mm. The welding speed was decreased linearly with the required the minimum input energy of laser input accordingly, the turning point appeared at the same position. The relationship between welding speed and laser power density was two linear segments and the turning point was 40 m/min, 6.50×10^5 W/cm^2.

Keywords: Fibre laser, Cr-plated sheet steel, laser welding, laser power density, welding speed

1 INTRODUCTION

Thin plates are used extensively in automotive, shipbuilding, and other industries. Welding technology is the main assembling method to manufacture thin plate structures because of its high productivity and ease of use. The industrial use of laser welding technology has been increasing due to the many advantages offered by its special features, which can offer lower heat inputs and faster cooling rates than traditional arc welding, which often requires

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multiple pass welding. The other major benefits of laser welding include high scanning velocity, a narrow heat affected zone (HAZ), low distortion, excellent controllability and the ability to produce a high-intensity heat source suitable for precision welding [1].

Derakhshan *et al.* [2] found that lower heat input could markedly influence the final distortion of the welded structure. And this conclusion could strongly support the idea of replacing traditional arc welding method with laser-based welding in many instances. Hekmatjou and Naffakh-Moosavy [3] found that hot cracks could be avoided by using a pulsed laser beam in a pre-heat status. Also, increasing the laser average power in fixed pulse frequency and pulse duration resulted in a significant reduction in hot cracking tendency in pulsed laser welding. Elmesalamy *et al.* [4] found that the application of the narrow gap laser welds technique could lead to significant reductions in both the magnitude of the peak tensile residual stresses. And the welding speed has a more significant influence on the width of the region sustaining tensile residual stresses than it does on the peak value of the stress. Frostevarg [5] found that as laser beam welds had many beneficial characteristics: a thinner root; the humping regime had a shorter window of operation and so both the humps and root sagging are reduced; limiting the size of the process exit minimises spatter; and while the melt flowed, the melt width and pressures in the keyhole were responsible for the final weld geometry. Liu *et al.* [6] found that the residual stresses on the outer and inner surfaces were tensile in the weld zone and its vicinity. The through-wall hoop residual stress within the weld was mostly tensile.

The problem of laser welding technology is the setting of the parameters. Kovacs [7] thought the welding gas used (Ar, CO_2, He, etc. and their mixes and percentages), the welding speed, the focus point and the power rate were the governing parameters, with the welded materials (chemical composition), sheet thickness and joint type also influencing the weld joint quality. Lin and Su [8] found the weld bead and HAZ of the weldments to be the weakest parts when joining aluminium alloys because the material had a tendency to form intergranular cracks under residual tensile stress and stress concentration caused by welding deformation easily formed crack sources. Wang and Song [9], and Zhang and Wu [10] found that the thermal cycles experienced caused the grain growth in the HAZ during the welding process, which resulted in a deterioration of the impact toughness at a low temperature and intergranular corrosion resistance property; therefore, the heat transfer process and temperature history had to be controlled carefully in welding ferrite stainless steel to reduce the HAZ width and grain size in the HAZ. Berger *et al.* [11] performed the interaction between laser beam and water or ice in order to observe directly the behavior of the capillary and the flow field in the weld pool. Several different regimes of bubble generation were found and the welding velocity played an important role in the bubble formation. Meng *et al.* [12] observed the keyhole and molten pool dynamic behavior in laser lap welding T-joints, and porosity was suppressed by maintaining a small gap or adopting high welding speed. Sun *et al.* [13] found that the shielding gas had a great influence on the porosity formation in the high power laser welds of 304L stainless steel: many pores were retained when Ar was used and almost no pores were found in the laser welds when N_2 or no shielding gas was used. According to Tzeng [14], the energy transmitted into the material in pulsed laser welding depends mainly on the following set of variables: laser peak power; pulse time; process speed; and the super position of consecutive pulses, known as the overlapping factor. The overlapping factor is calculated considering the process speed and the frequency of the pulses, synthesizing representatively the effect of a particular combination of process parameters.

With the increasing of the welding speed, welding defects occurred more readily, such as non-penetration, burn through and sag in thin plate (0.15 mm thick) laser welding. This study of high speed (>30 m/min) laser welding of thin plates has important application prospects. In view of the characteristics of thin plate welding, the laser welding experiments were carried out by adjusting and controlling the laser parameters of the welding process. The influence of the laser spatial distribution of high power laser welding on the quality of the weld was analysed and studied.

2 EXPERIMENTAL PROCEDURES

A 4 kW fiber laser welding machine (YLS-4000-S2T-TR; IPG Photonics Corporation) was used for the butt joint welding of a 0.235 mm thick Cr-plated steel sheet. The collimating lens focal length was 125 mm and the focusing lens focal length was 250 mm. The fiber core diameter was 0.3 mm. The fibre laser welding parameters are given in Table 2. The laser welding bench is shown in Figure 1 and the welding fixture is shown in Figure 2.

The chemical composition of the Cr-plated steel sheet is given in Table 1. The thickness of the Cr plating layer was 10 nm.

When the butt joint fibre laser welding speed was more than 40 m/min and if the laser was just focusing on the workpiece, it would lead to welding defects such as burn through of the weld. To avoid this, the focal point was changed to the positive defocus of 5 mm.

TABLE 1
The chemical constituents of the Cr-plated steel sheet used in this work (wt.%).

C	Si	Mn	Ni	Cr	S	P	Cu	Mo	Alt
0.0900	0.0100	0.5000	0.0084	0.0247	0.0120	0.0140	0.0192	0.0019	0.0470

TABLE 2
Fibre laser welding parameters used for Cr-plated steel sheet test pieces.

Laser Power (kW)	Weld Width (mm)	Welding Speed (m/min)	Defocusing Distance (mm)
0.72	0.58	10	0
1.30	0.58	20	0
1.90	0.58	30	0
2.50	0.62	40	0
3.50	0.80	45	+5
3.80	0.80	50	+5

FIGURE 1
Photograph of the fibre laser welding bench.

3 RESULTS AND DISCUSSION

The cross-section of a typical butt joint fibre laser weld produced with a defocusing distance of 0 mm and a laser power of 1.9 kW is shown in Figure 3. Figure 4 showed the hardness curves of weld and matrix regions were the hardness of the matrix was 180 $HV_{0.05}$ and the hardness of the weld was 360 $HV_{0.05}$.

For the tensile testing, all the tests were performed in accordance with GB/T228-2002, and the tensile test results of fibre laser welded specimens were given in Table 3. All samples were fractured at the non-welding zone, as shown in Figure 5, where the sample was prepared with the weld parameters

FIGURE 2
Photograph of the fixture used for the fibre laser butt joint welding tests.

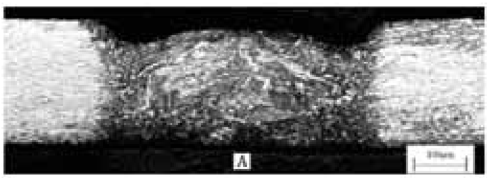

FIGURE 3
Cross-sectional optical micrograph of a typical butt joint fibre laser weld in the Cr-plated steel sheet produced at a defocusing distance of 0 mm and a laser power of 1.9 kW.

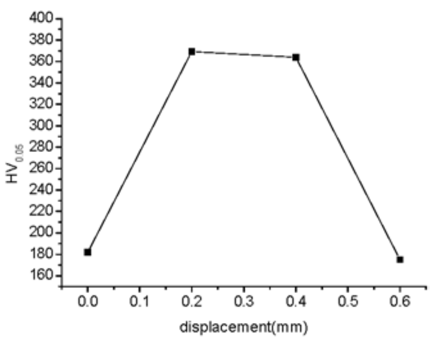

FIGURE 4
Graph showing the hardness curves of the fibre laser weld and the matrix regions.

of laser power of 1.9 kW and defocusing distance of 0 mm. It was found that the tensile strength of the weld was higher than that of the matrix.

When the welding speed was not more than 40 m/min and was linear with the required laser power. During welding, the input energy of the laser was fully used for the melting of the material and the weld pool was stable. With the increase of the welding speed, the required power density was too high

TABLE 3
Tensile test results of the fibre laser welded Cr-plated steel sheet specimens.

No.	Force (kN)	Elongation After Fracture (%)	Tensile Strength (MPa)	Fracture Position
1	1.24	13.5	422.0	Non-weld seam
2	1.26	16.5	429.0	Non-weld seam
3	1.26	12.5	429.0	Non-weld seam
4	1.25	12.0	425.5	Non-weld seam

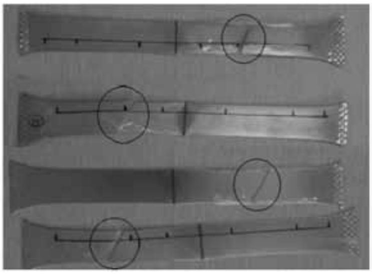

FIGURE 5
Photograph showing the fracture situation of a butt joint fibre laser welded Cr-plated steel sheet samples in the tensile tests.

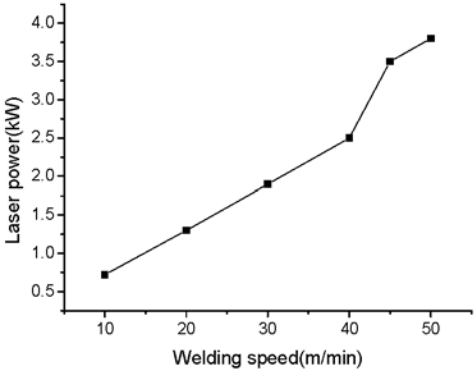

FIGURE 6
Graph showing the relationship between welding speed and fibre laser power.

and would easily cause material surface gasification and the loss of the material. When the focus position was changed to 5 mm, in order to ensure the time of laser action and the laser power density, the input power needed had to be increased. At this time, the inflexion point of the input power appeared, as seen in Figure 6.

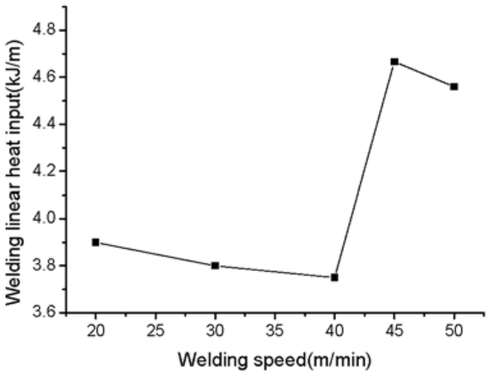

FIGURE 7
Graph showing the relationship between welding speed and welding linear heat input.

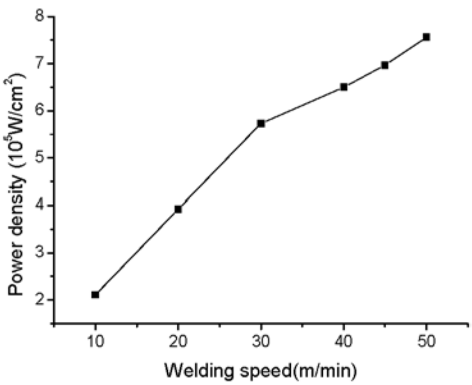

FIGURE 8
Graph showing the relationship between welding speed and fibre laser power density.

Figure 7 shows the relationship between the welding speed and the minimum laser input energy. With the increase of the power density, the energy density of the minimum line decreased, and the turning point appeared when the welding speed was 45 m/min, which was due to the increase of the focus position from the focal 0 to 5 mm at this time. At the turning point it was visible that the minimum input energy of laser input needed by the Cr-plated steel sheet was increased accordingly, when the weld width was increased. As weld width was increased, the laser power density was decreased accordingly when the power was kept constant. So the laser power needed was increased to keep the power density was the consistent. Thus, the minimum input energy of laser input was increased accordingly. When the welding speed was less than 40 m/min the relationship between welding speed and laser power density was linear. As the power density continued to increase, when the welding speed was 40 m/min, the linear relation appeared turning point, and the slope of the curve was reduced, as one can see from Figure 8. This was because when the power was increased to a certain value, which was not less than 6.50×10^5 W/cm^2 in these experiments, with the heating speed of the material was increased by the laser, the absorption rate of the laser was increased, which reduced the energy needed to maintain the stable molten pool.

4 CONCLUSIONS

The findings from the high speed laser welding of Cr-plated steel sheet in terms of the effects of laser parameters can be concluded as:

(i) It was found that the tensile strength of the weld was higher than that of the matrix;
(ii) The welding speed was increased linearly with the required laser power and the turning point appeared when the welding speed was 45 m/min. This was due to the increase of in the focus position from the 0 to 5 mm;
(iii) The welding speed was decreased linearly with the required minimum input laser energy and the turning point appeared when the focus position altered from 0 to 5 mm; and
(iv) The relationship between welding speed and laser power density was comprised of two linear segments and the turning point was 40 m/min, 6.50×10^5 W/cm^2.

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