Research on Residual Stress Distribution in Different Areas of Laser-MAG Arc Hybrid Welding by Numerical Simulation

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Abstract. In this research, through experiments and numerical simulations, the residual stress distribution of the top and bottom surfaces of the laser (TruDisk16002)-arc (MAG) hybrid welding seam and the weld cross-section are studied. The results show that when the arc power is 6.5KW and the laser power is 7.5KW, the weld is formed well. The residual stress on the bottom surface near the weld is higher than that on the top surface. The laser zone in the center of the weld has the largest residual stress, the arc zone is smaller, and the mixed zone is the smallest. The laser zone has the largest residual stress at the fusion line and the heat-affected zone, followed by the mixed zone, and the arc zone is the smallest. followed by the mixed zone, and the arc zone has the smallest.

1. Introduction

Laser-MAG arc hybrid welding has the superiorities of good process stability, less total thermal input, good clearance bridging ability and high production efficiency[1-4]. Zhang et al. [5]established the advantages of laser arc hybrid welding. The thermo-metallurgical-mechanical model predicts the temperature, structure, hardness and residual stress of laser hybrid arc welding. Kong et al. [6]used numerical simulation to simulate laser arc hybrid welding. It is found that the residual stress in the HAZ is higher than that in other places, and the appropriate increase of welding speed can reduce the residual stress.

The variation of residual stress at weld joints is studied in this paper. In this study, experiments and numerical simulations were used to study the laser (TruDisk16002)-arc (MAG) hybrid welding of AH36 steel with a 0mm gap. Study the weld formation by changing the laser power. The residual stress distribution and changes in different areas of the weld are studied in detail.

2. Experiment

2.1. Materials

This experiment uses AH36 steel sheet, the size of the butt joint test plate is 300×150×5mm, and the assembly gap is 0mm. Here the welding wire brand used is JM-56, that has a diameter of 1.2mm. The chemical composition of AH36 and welding wire is shown in Table 1.
Using laser (TruDisk16002)-Mag arc hybrid welding. Figure 1 is the welding equipment. The arc parameters are constant, and the laser power is 7KW, 7.5KW, and 8KW respectively. The protective gas is a mixture of CO2 (20%) + Ar (80%), and the gas flow rate is 20L/min. Table 2 shows the welding process parameters.

**Table 1. AH36 and JM-56 composition (wt.%)**

|        | C    | Si   | Mn   | Mo  | V   | P   | S   | Cu  | Ni  | Nb  | Ti  | Al  |
|--------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| AH36   | 0.157| 0.392| 1.501| -   | 0.030| 0.003| 0.014| 0.003| 0.015| 0.010| 0.002| 0.003| 0.042|
| JM-56  | 0.077| 0.87 | 1.45 | 0.002| 0.031| 0.004| 0.012| 0.013| 0.125| 0.017| -   | -   | -   |

**Table 2. Welding process parameters**

| Board thickness (mm) | Laser power (KW) | Arc current (A) | Arc voltage (V) | Welding speed (mm/s) | Defocus (mm) | Assembly clearance (mm) |
|----------------------|------------------|-----------------|-----------------|----------------------|--------------|------------------------|
| 5                    | 7                | 205             | 31.9            | 41.6                 | 0            | 0                      |
| 7.5                  | 7.5              | 205             | 31.9            | 41.6                 | 0            | 0                      |
| 8                    | 8                | 205             | 31.9            | 41.6                 | 0            | 0                      |

![Figure 1. Laser -MAG arc composite welding device](image1.png)

3. **Finite Element Model**

The simulation of temperature field and stress field is realized through the sequential coupling of thermal structure. The finite element modeling is shown in Figure 2.

![Figure 2. Finite element model](image2.png)
MAG adopts Gaussian surface heat source, the expression is as formula (1):

\[
Q_{arc}(x, y) = \frac{3P_{arc}}{\pi r_{arc}^2} \exp \left[ - \frac{3(x^2 + y^2)}{r_{arc}^2} \right]
\]  

(1)

The laser uses a Gaussian cylinder heat source, the expression is as formula (2):

\[
Q_{laser}(x, y) = \frac{3P_{laser}(H - \beta h)}{\pi r_{laser}^2(2 - \beta)} \exp \left[ - \frac{3(x^2 + y^2)}{r_{laser}^2} \right]
\]

(2)

In the above formula: \(P_{arc}\) is the arc power; \(P_{laser}\) is the laser power; \(r_{arc}\) is the radius of the arc heat source; \(r_{laser}\) is the radius of the laser heat source; \(\beta\) is the attenuation coefficient; \(H\) is the effective depth of the laser heat source.

4. Results and Discussion

4.1. Weld Formation

During the experiment, the MAG power remained unchanged. By changing the laser power, 7.0KW, 7.5KW and 8.0KW were used to complete the welding seam. From Figure 3.(a)(b)(c), when the laser power is 7KW and 8KW, the bottom of the weld has an unpenetrated part, the top shape is uneven, and there is undercut. At 7.5KW, the bottom of the weld is penetrated and formed beautifully, and the top is formed evenly.

![Figure 3](image_url)

**Figure 3.** Comparison of welded joints under different laser powers (a), (b) and (c) are the weld formation under 7KW, 7.5KW, and 8KW respectively

Comparison between numerical simulation and measured weld profile

It can be seen from Figure 4 that both numerical simulations and experiments show typical nail-shaped joints. The simulated weld area and heat-affected zone are consistent with the experimental results. This indicates the correct shape of the numerical model.

![Figure 4](image_url)

**Figure 4.** Comparison of experimental and simulated weld profile
4.2. Residual Stress
Figure 5 (a) is a schematic diagram of the location of the weld residual stress test. Figure 5(b) is a comparison diagram of experimental and simulated longitudinal residual stress. It can be seen from the figure that the residual stress on the top surface of the weld is smaller than the bottom surface in both the experiment and the simulation. And the simulated value is slightly higher than the experimental value, which is mainly due to the simplification of the model by the simulation. Figure 5(c) is the simulation value of the transverse residual stress. It can be seen from the figure that the residual stress on the top surface is smaller than the bottom surface within 65mm from the weld. After 65mm, the residual stress on the top surface is greater than the bottom surface, and the stress gradient on the top surface is smaller than the bottom surface.

![Figure 5](image)

**Figure 5.** Experimental and simulated residual stress (a) Schematic diagram of the residual stress test location; (b) comparison of the average longitudinal residual stress between the experimental and simulated top and bottom surfaces; (c) the comparison of simulated transverse residual stress

Figure 6 shows the residual stress and change rule of the weld cross section. The black line in the figure is the test position corresponding to the upper arc area in the schematic diagram, the red line is the test position corresponding to the laser arc mixing zone in the middle of the schematic diagram, and the blue line is the schematic diagram. For the test position corresponding to the lower laser zone, the figure shows that the residual stress in the laser zone in the center of the weld is the largest, the arc zone is smaller, and the mixed zone is the smallest. The laser zone has the largest residual stress at the fusion line and the heat-affected zone, followed by the mixed zone, and the arc zone is the smallest.
Figure 6. Variation trend of residual stress from the weld center to the heat-affected zone at the junction of arc and laser

5. Conclusions
In this study, the weld formation was studied through laser-MAG arc hybrid welding. Through numerical simulation, and through simulation, the residual stress distribution at the weld is studied.

(1) When the arc power is 6.5KW and the laser power is 7.5KW, the weld is formed well.
(2) The bottom surface of the residual stress near the weld is greater than the upper surface.
(3) The laser zone in the center of the weld has the largest residual stress, the arc zone is smaller, and the mixed zone is the smallest.
(4) The laser zone has the largest residual stress at the fusion line and the HAZ, followed by the mixed zone, and the arc zone is the smallest.

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