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Experimental investigation of hybrid laser arc welding of X80 pipeline steel

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Abstract. Hybrid laser/MIG welding was carried out for API X80 pipeline steel using different welding parameters. Influence of welding current on weld appearance, microstructure variation and hardness across the weld cross-section was investigated. Increasing welding current is beneficial for larger weld penetration and high welding efficiency. However, increase of welding current can result in coarser microstructures in CGHAZ near ArcZ. Maximum hardness value occurs in the vicinity of fusion zone of LaserZ, and a slight reduction is observed with larger welding current.

1. Introduction

Recently, the increasing oil and natural gas demand advances minimized wall thickness, larger diameter and increasing operating pressure. This can be realized by material substitution, from most applied API X65 and X70 steels to X80 and X100 steels. In China, API X80 steels have been developed and applied successfully and widely in the West-East Gas Pipeline Projects [1, 2]. The most commonly used welding methods in field welding of pipelines are shield metal arc welding (SMAW), flux core arc welding (FCAW) and gas metal arc welding (GMAW) [3]. However, these welding techniques are more or less time consuming and laborious, and welding defects like porosity, distortion and cracks may occur sometimes. Thus an innovative hybrid welding technique is developed which is highly efficient. Hybrid laser arc welding (HLAW) combines the benefits of both laser welding and arc welding, providing increasing fully penetrated root pass depth and welding speed with less distortion. This new welding technique allows for full penetration of medium to heavy thickness plates achieved by a single pass [4-6]. For the pipeline field welding, HLAW can be a promising alternative approach to manufacture pipes with relative low heat input, small heat affected zone (HAZ) and high welding efficiency.

In the present study, HLAW experiment was conducted using medium thickness X80 steel plates. Weld geometry, microstructure and hardness distribution in the welded joint was analyzed. The effects of welding current on the weld geometry, microstructure and hardness distribution in heat affected zone (HAZ) were clarified.
2. Experimental procedures

The base metal employed is 27.5 mm-thick API X80 steel and its chemical composition is given in Table 1. The specimens were prepared with dimensions of 200mm×100mm×27.5 mm. The hybrid welding system consisted of a 10 kW fiber laser system and a Fronius MIG arc welding machine. The angle between the electrode and the workpiece surface was 60°. A defocusing distance of -2 mm was used in the experiment. The hybrid welding system was set in a laser-leading position. The welding parameters are as follows: laser power = 5 kW, travelling speed = 0.6 m/min, voltage range = 20-22 V and initial gap = 0.5mm. To study the effect of welding current on characteristics of the work-pieces, three different welding currents (150A, 180A, and 220A) and square groove butt joints were selected. The filler wire used in the investigation is ER307Mo with a diameter of 1.2 mm. To compare the effect of welding technique on welding geometry, bead-on-plate welding was conducted using a welding current of 220A and laser power of 5 kW.

Table 1. Chemical composition of X80 pipeline steel (wt, %).

|   | C     | Si    | Mn    | Cr    | Nb    | Ni    | Cu    |
|---|-------|-------|-------|-------|-------|-------|-------|
|   | 0.052 | 0.203 | 1.69  | 0.209 | 0.095 | 0.120 | 0.188 |
| Mo | 0.003 | P     | 0.004 | V     | Ti    | Al    | N     |
|   | <0.0005 |       |       |       |       |       |       |

The weld geometries were examined for all the work-pieces, and then specimens were mechanically polished and etched with 2% nital reagent. Cross-sectional geometry parameters were examined using a stereoscope. Observation of microstructures in the welded joints was conducted using optical microscope. The hardness distribution in the specimens was measured using the micro-Vickers hardness test, with a load of 200 g and 15 s of loading time.

3. Experimental results

Appearance of bead-on-plate welds and cross-sections using different welding techniques are shown in Fig. 1 and Fig. 2, respectively. It can be seen from Fig. 2 (a) that hybrid weld is composed of relatively wide upper arc zone (ArcZ) and relatively narrow lower laser zone (LaserZ). It is also seen that the MIG weld is much shallower compared to HLAW weld and laser weld. The penetration of HLAW weld is larger than the other two welds. The widths of HLAW weld and MIG weld are comparable.

![Figure 1. Appearance of the welds (a) HLAW (b) laser (c) MIG.](image)

Weld appearances and cross-sections of square groove butt joints under different welding current are shown in Fig. 3 and Fig. 4, respectively. Hybrid weld bead geometry parameters are summarized in Table 2. It can be seen that the weld width, penetration and reinforcement height increase with the welding current. In order to achieve high welding efficiency, 220 a welding current is preferred. However, experimental results show that spatter in the welding process increases with welding current larger than 230A which is not ideal for the welding quality.
Microstructures in different HAZ zones of the hybrid-welded joint with different welding current are presented in Fig. 5 and Fig. 6. It can be seen from Fig. 5 and Fig. 6 that the coarse grained HAZ (CGHAZ) near ArcZ is mainly composed of lath bainite and granular bainite. The microstructure in CGHAZ near LaserZ is also composed of lath bainite and granular bainite, but with smaller grain size. The microstructure in fine grained HAZ (FGHAZ) near ArcZ reveals a predominantly bainitic structure and a few grain boundary ferrite. The microstructure in FGHAZ near LaserZ is mostly composed of granular bainite and some polygonal ferrite. Comparing Fig. 5 and Fig. 6, it is found microstructure in ArcZ CGHAZ is coarser with larger welding current.

![Figure 2](image1.png)

**Figure 2.** Cross-sectional appearance of the welds (a) HLAW (b) laser (c) MIG.

![Figure 3](image2.png)

**Figure 3.** Appearance of hybrid welds (a) 150A (b) 180A (c) 220A.

![Figure 4](image3.png)

**Figure 4.** Cross-sectional appearance of hybrid welds (a) 150A (b) 180A (c) 220A.

| Welding Current $I$ (A) | Weld bead width $B$ (mm) | Weld bead penetration $H$ (mm) | Reinforcement height $H$ (mm) |
|--------------------------|--------------------------|-------------------------------|-------------------------------|
| 150                      | 7.46                     | 7.58                          | 2.10                          |
| 180                      | 7.62                     | 8.15                          | 2.24                          |
| 220                      | 8.34                     | 8.95                          | 2.47                          |
Figure 5. Microstructures in the welded joint with 150A welding current (a) CGHAZ near LaserZ (b) FGHAZ near LaserZ (c) CGHAZ near ArcZ (d) FGHAZ near ArcZ.

Figure 6. Microstructures in the welded joint with 220A welding current (a) CGHAZ near LaserZ (b) FGHAZ near LaserZ (c) CGHAZ near ArcZ (d) FGHAZ near ArcZ.

Vickers hardness distribution across the welded joint with welding current of 150A is illustrated in Fig. 7. It is observed that hardness variations in upper arc zone and lower laser zone are different, and the phenomenon can be attributed to difference in temperature histories experienced at different regions during welding. Maximum hardness appears near the fusion line for both zones. Maximum hardness
value in the laser zone is higher than that in the arc zone. It is also found that maximum hardness decreases slightly with increasing welding current.

![Hardness distribution](image)

**Figure 7.** Hardness distribution in the welded joint with 150A welding current.

### 4. Conclusion

(1) Hybrid laser/MIG welding of advanced X80 pipeline steel was investigated using bead-on-plate welding and square butt welding. Weld geometry, microstructure and hardness distribution in hybrid welded joints under different welding current were reported.

(2) The penetration of HLAW weld is larger than that of laser weld and MIG weld. It is concluded that weld width, penetration and reinforcement height increase with the welding current. Microstructures in CGHAZs are mainly composed of bainite, and microstructure in arc CGHAZ is coarser than that in laser CGHAZ. As welding current increases, arc CGHAZ microstructures become coarser.

(3) Maximum hardness in laser zone is higher than that in the arc zone. Maximum hardness value in HAZ slightly decreases with increasing welding current.

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