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Effects of beam configurations on wire melting and transfer behaviors in dual beam laser welding with filler wire

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ABSTRACT

Butt joints of 2 mm thick stainless steel with 0.5 mm gap were fabricated by dual beam laser welding with filler wire technique. The wire melting and transfer behaviors with different beam configurations were investigated detailedly in a stable liquid bridge mode and an unstable droplet mode. A high speed video system assisted by a high pulse diode laser as an illumination source was utilized to record the process in real time. The difference of welding stability between single and dual beam laser welding with filler wire was also compartively studied. In liquid bridge transfer mode, the results indicated that the transfer process and welding stability were disturbed in the form of "broken-reformed" liquid bridge in tandem configuration, while improved by stabilizing the molten pool dynamics with a proper fluid pattern in side-by-side configuration, compared to sigle beam laser welding with filler wire. The droplet transfer period and critical radius were studied in droplet transfer mode. The transfer stability of side-by-side configuration with the minium transfer period and critical droplet size was better than the other two configurations. This was attributed to that the action direction and good stability of the resultant force which were beneficial to transfer process in this case. The side-by-side configuration showed obvious superiority on improving welding stability in both transfer modes. An acceptable weld bead was successfully generated even in undesirable droplet transfer mode under the present conditions.

1. Introduction

Laser welding, as a promising joining technique, has gained considerable acceptance in many industries especially for tailor welded blanks (TWBs) in automotive industry due to its increased productivity and good flexibility [1]. In the production of TWBs, steel sheets are typically welded in butt joint configuration. However, owing to the small focal spot diameter of laser beam, it needs precise fit-up requirement to guarantee the weld quality. Moreover, the gap-bridging capability, which is an important factor on influencing the weld quality and productivity, is also significantly restricted. The largest accepted gap in butt joint is usually 10% of sheet thickness for traditional single beam laser welding, which is often difficult to reach. Previous studies indicated that two effective welding methods, which were dual beam laser welding (DBLW) and single beam laser welding with filler wire (LWFW), could improve the gap-bridging capability obviously [2–5].

Related studies indicated that the use of DBLW could improve gap-bridging capability effectively compared to conventional single beam laser welding. Longfield et al. [2] employed this technique to join 2.5 mm thick butt joint and reported that the gap tolerance increased from 0.2 to 0.4 mm compared to single beam laser welding; this technique was also successfully applied to the industrial production of steel coil joining. For DBLW, the arrangement, interbeam spacing, and energy distribution of dual laser beams can be adjusted flexibly; thereby, a proper beam configuration can be designed for diversiform butt joints with gaps. This characteristic of DBLW results in the increased gap tolerance. In adition to this, DBLW can also improve weld quality effectively in the form of improving weld appearance [6,7], reducing porosity [8], and inhibiting cracking susceptibility [9]. LWFW is another effective way to improve gap-bridging capability [3–5]. The use of additional filler wire provides enough material to fill the gaps and thereby leads to a higher gap tolerance than that of without filler wire. A 2 mm carbon steel thick butt joint with reached up to 1 mm wide air gap was successfully welded by using a CO_2 laser with filler wire [5].

The above mentioned results indicate that both DBLW and LWFW can improve the gap-bridging capability of single beam laser welding effectively. Therefore, a dual beam laser welding with filler wire (DBFW) technique is logically proposed to promote the gap-bridging capability further. But only few publications have mentioned the technique and study its gap-bridging capability. Aalderink et al. [10] compared the gap-bridging capability of different laser welding tech-

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Table 1
Chemical compositions of base metal and filler wire (in wt%).

	C	Mn	Si	Cr	Ni	Mo	Cu	P	S	Ti	Fe
321 SS	0.045	1.08	0.47	17.02	9.02	–	–	0.034	0.0065	0.22	Bal.
ER321	0.049	1.47	0.50	19.05	9.10	0.46	0.15	0.024	0.020	0.50	Bal.

niques through the welding of 1.1 mm thick aluminum sheets butt joints. The result showed that the gap tolerance increased to 0.6 mm further by using twin-spot laser welding with cold wire feeding, compared to that of 0.4 mm for LWFW process. It definitely proved that the DBFW technique could combine the superiority of these two techniques in gap-bridging capability.

For laser welding with filler wire process, there exist numerous technical parameters about the positioning of filler wire, so it is difficult to guarantee the process stability during welding. Most studies [11–14] have focused on the influence of welding parameters on weld quality. Salminen et al. [11–13] reported that wire feeding position and feeding angle were two important factors affecting the process stability, and inaccurate positioning of filler wire could increase the reflectivity of laser and deteriorate the weld quality. Syed [14] studied the effects of wire feeding direction and location on weld quality and found that wire feeding in the front direction and at the leading edge of the melt pool preferred to obtain a better weld quality. For DBFW technique, the welding process becomes more flexible because of the additional welding parameters of dual beam configuration, which is a very important factor.

In order to study the influence of wire feeding position on weld quality, rsearchers started to pay attention to the wire melting dynamics which was closely related to the process stability and weld quality [15–17]. High speed imaging technique is very useful to observe the wire melting and transfer behavior. Based on this technique, Yu et al. [15] revealed that the melting dynamics of LWFW were characterized as explosion, big droplet and molten metal bridge according to the distance between the filler wire and laser beam in the welding direction. It was concluded that molten metal bridge could guarantee a stable welding process and good weld quality, while big droplet transition led to disturbed stability and unacceptable weld quality. Tao et al. [16] studied the wire melting behavior and process stability in fiber laser welding of T-joints and similar results were obtained. It was reported that liquid bridge transfer mode was superior to droplet transfer mode with more stable welding process which resulted in better weld appearance and lower porosity defect. Takahashi et al. [17] studied the filler wire meltig dynamics during CO_2 laser welding of aluminum alloys using a high-speed shadowgraph imaging technique and also found that humping defect were formed with droplet transfer.

Based on the above analyse, it was indicated that there were mainly two wire transfer modes in LWFW process: liquid bridge mode and droplet mode. The liquid bridge mode could lead to a stable welding process and good weld quality, while the droplet mode was inherently unstable and resulted in undesirable weld beads. However, in the practical production, this transfer mode is unavoidable due to restriction of assembly accuracy. So how to inhibit the welding unstability in droplet transfer mode also needs to be studied. Although some researchers had applied the high speed imaging technique to observe the melting wire transfer behaviors, the captured images were still not clear enough to describe the whole process clearly and detailedly. Besides that, to the best of our current knowledge, no results of wire melting and transfer behaviors in DBFW technique have been reported.

In this work, a 2 mm thick stainless steel butt joint with 0.5 mm gap was welded by DBFW technique. The objective of this work was to investigate the effects of dual beam configurations on wire melting and transfer behaviors in different transfer modes. Meanwhile, the difference of melting dynamics between DBFW and LWFW was also compartively studied. The research findings provided more clear understanding for improving process stability and weld quality.

2. Materials and experimental procedure

2.1. Material

2 mm thick 321 stainless steel (SS) sheets with the dimension of 150 mm (length)×75 mm (width) were used in this study. The commerical ER321 stainless steel filler wire with the diameter of 1.2 mm was utilized. Their chemical compositions are listed in Table 1. A butt joint with 0.5 mm air gap was adopted in all experiments.

Before welding, the surface of stainless steel sheets were polished by abrasive paper for removing the oxides, and then wiped with industrial alcohol.

2.2. Experimental setup

Fig. 1 shows the experimental setup of DBFW including a dual beam laser welding system, a wire feeding system and a high speed image acquisition system.

The dual beam laser welding system mainly consists of an YW50 welding head based on modular design. The dual laser beams were achieved by a beam splitting module positioned in the welding head, which were then arranged in tandem configuration or side-by-side configuration (as shown in Fig. 1). The interbeam spacing L was kept constant at 0.6 mm. The welding experiments were performed using a continuous wave solid-state Ytterbium fiber laser (YLS-10000, IPG Laser GmbH) with a maximum power of 10 kW. The wavelength of fiber laser is 1.07 μm. A focusing lens of 200 mm and a collimating lens of 150 mm were used to focus the laser beam. The spot diameter of single laser beam at the focal length is 0.26 mm, and the focusing plane was positioned at the surface of workpiece. The spot diameters of the split dual laser beams were treated as the same as that of single laser beam because they used the same collimating lens and focusing lens. In the experiment, the total laser power of the single beam was 1500 W,

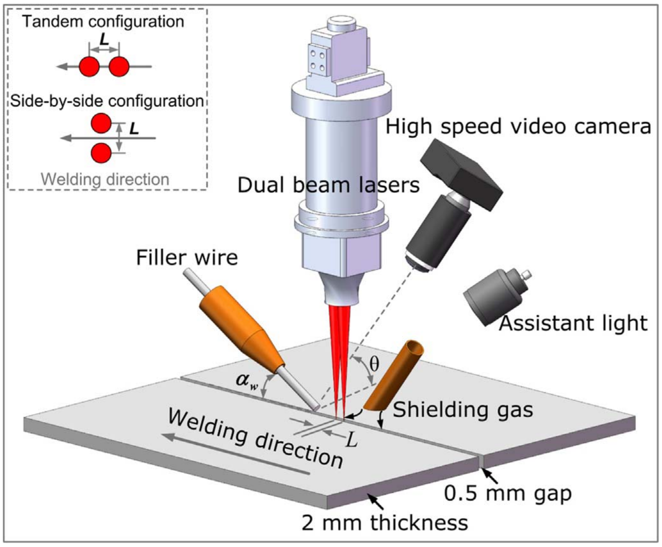

Fig. 1. Schematic of experimental setup for DBFW.