超声模式对 GMAW 短路过渡行为与焊缝成形的影响

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摘要: 文中研究了连续输出的超声与脉冲输出的超声对 GMAW 短路过渡行为与焊缝成形的影响. 结果表明, 焊接过程中引入连续超声与脉冲超声均能改善 GMAW 短路过渡行为与焊缝成形. 两种模式对熔滴过渡行为的影响基本一致; 在焊缝成形方面, 连续超声对于焊缝熔深的影响更为显著. 具体结果为普通 GMAW 短路过渡周期约为 86.5 ms; 连续超声辅助 GMAW 短路过渡周期约为 79 ms; 脉冲超声辅助 GMAW 短路过渡周期约为 76.5 ms. 普通 GMAW 的熔宽为 5.06 mm、熔深为 0.361 mm, 焊缝余高为 1.253 mm. 与普通 GMAW 相比, 连续超声辅助 GMAW 焊缝熔宽减小了 0.4 mm, 焊缝熔深增加了 100%; 脉冲超声辅助 GMAW 焊缝熔宽减小了 0.19 mm, 焊缝熔深增加了 67.6%.

关键词: 连续超声; 脉冲超声; GMAW; 短路过渡; 焊缝成形
中图分类号: TG 444 **文献标识码:** A **doi:** 10.12073/j.hjxb.20190124004

0 序言

熔化极气体保护焊 (gas metal arc welding, GMAW) 具有焊接效率高、焊接速度快、焊缝质量高以及易实现自动化生产等优点, 被广泛应用于汽车、高速列车、航天航空等领域. 为了能够获得更加优质、高效的焊接方法, 相关学者开发了与之对应的复合焊接方法. 如激光电弧复合焊接[1-5]、超声电弧复合焊接等[5-6].

激光-MIG 复合焊接既具有高能束焊接速度高、熔深大的优点, 又利用电弧焊接搭桥能力强、适应性强的特点, 产生能量协同效应. 激光通过引导电弧改变等离子流力的方向, 改变熔滴过渡频率. 超声-GMAW 电弧复合焊接作为一种较新型的复合焊接方法, 近年来备受关注[7-9]. 已有研究表明在声辐射力的作用下电弧会发生明显收缩, 熔滴过渡频率增加; 同时, 受超声空化效应的影响, 焊缝晶粒明显细化, 焊接接头性能显著改善[10-11].

上述超声电弧复合焊接中其超声输出模式多为连续输出, 而不同输出模式的超声对于电弧焊接过程有何作用, 是否具有相同的影响规律还有待探讨研究. 因此, 文中通过控制焊接参数实现 GMAW 短路过渡, 以 GMAW 短路过渡为例. 研究连续输出的超声与脉冲输出的超声对于 GMAW 熔滴过渡行为与焊缝成形的影响. 揭示不同输出模式的超声对于 GMAW 短路过渡中的熔滴过渡行为与焊缝成形的影响规律. 为今后能够更加系统的、深入的研究超声输出模式对电弧焊焊接过程的影响打下坚实的基础.

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1 试验方法

试验母材为 Q235 低碳钢, 尺寸规格为 100 mm × 100 mm × 4 mm. 焊丝采用直径 1.2 mm 的 H08MnSi 焊丝. 焊前采用机械清理方式将母材表面氧化物及污物清除干净, 焊接形式为堆焊. 焊接电源是肯比公司生产的 ProMIG500 电源. 超声波源为课题自行设计, 额定功率为 2 000 W, 超声频率为 19 500 Hz, 超声输出模式分为连续超声与脉冲超声. 超声辅助 GMAW 焊接系统如图 1 所示. 焊丝由换能器中心孔同轴穿过, 超声由换能器端面发出, 换能器端面与工件之间将会形成超声场, 熔滴过渡将在超声场内完成.

试验焊接参数为送丝速度 5 m/min, 焊接电压 25 V, 焊接速度 4.5 m/min, 保护气体流量 15 L/min (10%CO_2 + 90%Ar), 可以实现熔滴的短路过渡. 根据课题组前期研究, 确定了声场参数. 连续超声声场参数: 发射端高度 30 mm, 喷嘴高度 11 mm; 脉

冲超声声场参数：发射端高度 30 mm，喷嘴高度 11 mm，输出频率 100 Hz. 采用 Optronis 公司生产的 CamRecord 5 000 × 2 高速摄像机对熔滴过渡行为进行拍照观察，频率为 2 000 fps，自动曝光. 短路过程的焊接电流通过 LT1005-S 霍尔电流传感器采集，并利用 USB2813 数据采集卡将数据传输到计算机，采集频率为 1.15 kHz. 焊接完成后，利用线切割技术截取焊缝横截面制备金相，金相腐蚀液为 4% 的硝酸. 采用光学显微镜对焊缝截面进行拍照，并测量焊缝熔宽、熔深等成形参数.

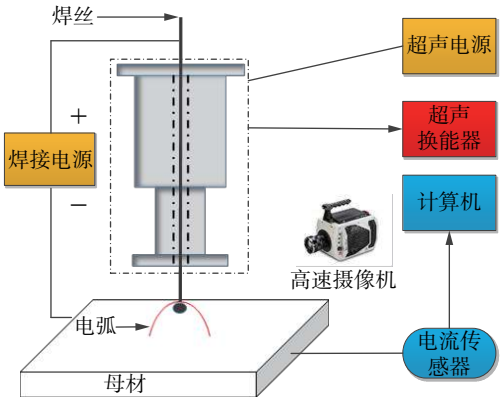


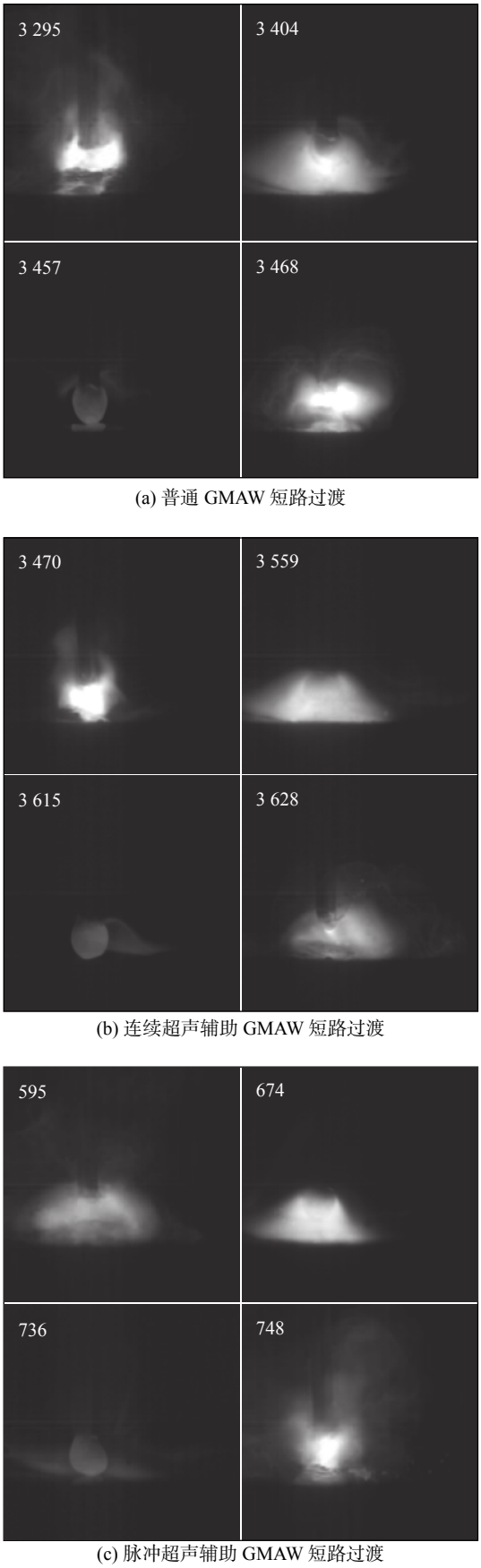
图 1 超声辅助 GMAW 系统

Fig. 1 Schematic of ultrasonic assisted GMAW system

2 试验结果与分析

2.1 熔滴过渡行为

图 2 为普通 GMAW、连续超声辅助 GMAW 与脉冲超声辅助 GMAW 短路过渡过程高速摄像照片. 从图中可以看出，引入连续超声与脉冲超声 GMAW 熔滴过渡过程的中的焊接电弧发生了明显的压缩. 这是因为超声发射端与母材之间形成了一个稳定的驻波声场，声场的存在能够影响电弧等离子体分布，文中的声场对电弧等离子起到了压缩的作用. 电弧发生压缩，能量更加集中将会对焊接熔滴过渡行为产生明显的影响. 熔滴过渡周期以一次液桥断裂到二次液桥断裂所需的时间为准. 从图中可以看出，普通 GMAW 短路过渡周期约为 173 fps (即 86.5 ms)，连续超声辅助 GMAW 短路过渡周期约为 158 fps(即 79 ms)，脉冲超声辅助 GMAW 短路过渡周期约为 153 fps(即 76.5 ms). 超声的引入明显缩短了 GMAW 短路熔滴过渡频率，其中脉冲超声的作用要略好于连续超声. 文献 [7] 研究了连续超声对铝合金熔滴过渡行为的影响，发现超声的



(a) 普通 GMAW 短路过渡

(b) 连续超声辅助 GMAW 短路过渡

(c) 脉冲超声辅助 GMAW 短路过渡

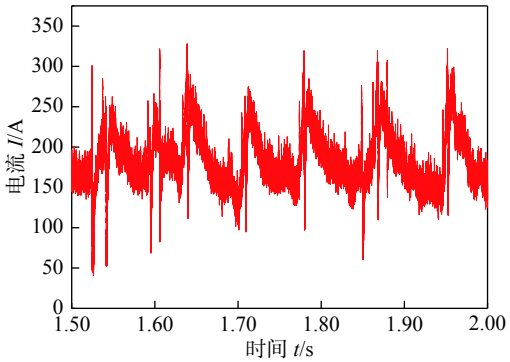
图 2 GMAW 短路过渡过程 (2 000 fps/s)

Fig. 2 Process of GMAW short circuit transfer. (a) traditional GMAW; (b) continuous ultrasonic assisted GMAW; (c) pulsed ultrasonic assisted GMAW

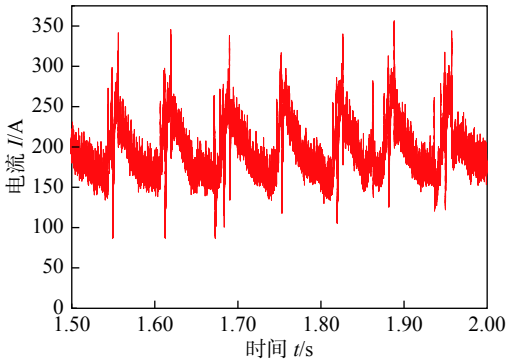
引入除了能够缩短熔滴过渡周期，熔滴尺寸也会发生明显减小. 文中亦对熔滴尺寸进行了观察，图 2 中每个参数下的第三张熔滴过渡图片为短路发生时的熔滴形貌. 从图中可以看出，不同参数短路发生时的熔滴尺寸大小基本一样，并未发生明显的变化. 这可能是因为熔滴过渡周期的减小程度较小，从而引入的超声对熔滴大小的影响不明显所造成的.

2.2　电信号分析

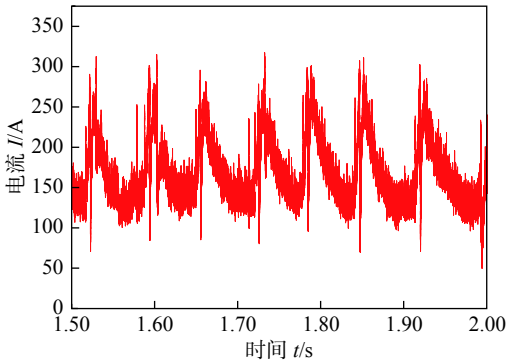
图 3 为普通 GMAW、连续超声辅助 GMAW 与脉冲超声辅助 GMAW 在 0.5 s 内的短路过渡过程的电流波形. 从图中可以看出，连续超声与脉冲超声



(a) 普通 GMAW 短路过渡



(b) 连续超声辅助 GMAW 短路过渡



(c) 脉冲超声辅助 GMAW 短路过渡

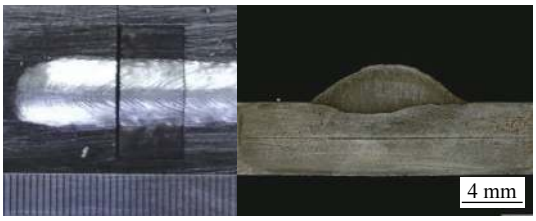
图 3　短路过渡电流信号

Fig. 3　Current signals of short circuit transfer. (a) traditional GMAW; (b) continuous ultrasonic assisted GMAW; (c) pulsed ultrasonic assisted GMAW

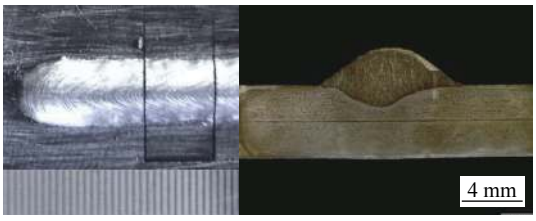
比普通焊接的电流波形更加均匀，说明引入超声能够使得焊接更加稳定. 在 0.5 s 普通 GMAW 存在 6 个电流波形周期，连续超声辅助 GMAW 存在 7 个电流波形周期，脉冲超声辅助 GMAW 存在 7 个电流波形周期. 加入超声后，单位时间内的短路过渡频率增大，与熔滴过渡行为的观察结果一致 (图 2).

2.3　焊缝成形

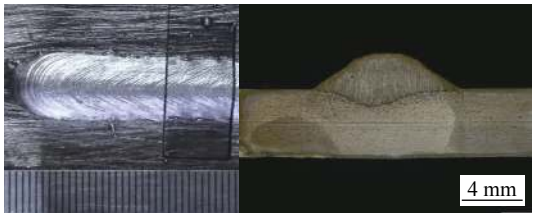
图 4 为普通 GMAW、连续超声辅助 GMAW 与脉冲超声辅助 GMAW 焊缝成形. 从图中可以看出，三者工艺下的焊缝表面成形较好，焊缝表面分布着均匀的鱼鳞纹，焊缝表面存在少许飞溅. 从焊缝截面可以看出，普通 GMAW 的熔宽为 5.06 mm、熔深为 0.361 mm，焊缝余高为 1.253 mm；连续超声辅助 GMAW 的熔宽为 4.66 mm、熔深为 0.723 mm，焊缝余高为 1.25 mm；脉冲超声辅助 GMAW 的熔宽为 4.87 mm、熔深为 0.605 mm，焊缝余高为 1.23 mm.



(a) 普通 GMAW



(b) 连续超声辅助 GMAW



(c) 脉冲超声辅助 GMAW

图 4　焊缝成形

Fig. 4　Weld appearance. (a) traditional GMAW; (b) continuous ultrasonic assisted GMAW; (c) pulsed ultrasonic assisted GMAW

与普通 GMAW 相比，连续超声与脉冲超声对于焊缝余高的大小基本无影响，焊缝余高的变化仅在 0.02 mm 左右. 连续超声与脉冲超声对于焊缝熔宽的影响较为弱，连续超声辅助 GMAW 焊缝熔宽减小了 0.4 mm，脉冲超声辅助 GMAW 焊缝熔宽减

小了 0.19 mm. 连续超声与脉冲超声对于焊缝熔深的影响极为明显，连续超声辅助 GMAW 焊缝熔宽增加了 100%，脉冲超声辅助 GMAW 焊缝熔深增加了 67.6%.

3 分析与讨论

以上研究可知，连续超声辅助 GMAW 与脉冲超声辅助 GMAW 改善了 GMAW 焊接过程与焊缝成形. 在熔滴过渡与电信号观察时发现，连续超声与脉冲超声的引入减小了熔滴过渡周期，增大了短路峰值电流. 但是由于熔滴过渡周期缩短程度有限，所以未对焊丝熔覆产生较大影响，因此各焊缝表面的成形情况基本一致. 文献 [7] 指出，在焊接过程过引入连续超声波后，在声辐射力的作用下电弧会发生压缩，压缩后的电弧能量更加集中，穿透能力更强，因此会获得更深的焊缝熔深. 通过研究发现，连续超声辅助 GMAW 焊缝的熔深明显增加，脉冲超声的引入也能够显著提高焊缝熔深. 由此可以说明，在 GMAW 焊接过程中，引入脉冲超声也能够对焊接过程进行控制，但是由于脉冲超声辅助 GMAW 焊接过程中超声声场间隔存在，对焊接电弧不能持续压缩，因此其对焊缝熔深的影响稍弱于连续超声辅助 GMAW.

4 结论

(1) 普通 GMAW 短路过渡周期约为 86.5ms，连续超声辅助 GMAW 短路过渡周期约为 79 ms，脉冲超声辅助 GMAW 短路过渡周期约为 76.5 ms.

(2) 普通 GMAW 的熔宽为 5.06 mm、熔深为 0.361 mm，焊缝余高为 1.253 mm. 与普通 GMAW 相比，连续超声辅助 GMWA 焊缝熔宽减小了 0.4 mm，焊缝熔深增加了 100%；脉冲超声辅助 GMAW 焊缝熔宽减小了 0.19 mm.，焊缝熔深增加了 67.6%.

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MAIN TOPICS, ABSTRACTS & KEY WORDS

Dynamic characteristics analysis of resistance spot welding pressure signal of aluminum alloy CHEN Shujun, HAO Jian, LI Fang, WU Na (Engineering Research Center of Advanced Manufacturing Technology for Automotive Components, Ministry of Education, Beijing University of Technology, Beijing, 100124, China). pp 1-6

Abstract: Based on an information acquisition system, the dynamic characteristics of the pressure signal for resistance spot welding of aluminum alloy. The pressure signals of splashing spot and normal spot are compared and analyzed in time and frequency domains. It was found that there is a sudden change in the pressure signal of splashing spot with obvious characteristic frequency, while the normal spot has no such phenomenon; The db5 wavelet is used to decompose the pressure signal into seven levels to obtain the waveforms in time and frequency domains and the energy ratio of detail signals in different frequency bands. The results showed that according to different forms and characteristics of the pressure signal, the standard deviation of the pressure signal during the power phase, the peak-peak value in the target level, the highest value of the energy ratio and the number of level in the target layer of the wavelet decomposition detail signal can be extracted as the characteristic index to identify splashing spot.

Key words: aluminum-alloy spot welding; pressure signal; frequency domain analysis; wavelet analysis; characteristic index

Effect of ultrasonic mode on GMAW short circuiting transfer and weld appearance CHEN Chao, FAN Chenglei, LIN Sanbao, YANG Chunli (State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin,150001, China). pp 7-10

Abstract: In this paper the influence of the continuous ultrasonic (CU) and pulsed ultrasonic (PU) on GMAW short circuiting transfer and weld appearance was studied. The results revealed that the continuous ultrasonic and pulsed ultrasonic could improve the short circuiting transfer process and weld appearance. The effect of the continuous ultrasonic on droplet transfer cycles was consistent with that of the pulsed ultrasonic. The effect of the continuous ultrasonic on weld appearance was more significant than that of the pulsed ultrasonic. The results showed that the droplet transfer cycles of GMAW, CU-GMAW and PU-GMAW are 86.5 ms, 79 ms and 76.5 ms, repectively. The weld width and weld penetration of GMAW is 5.06 mm and 0.361 mm. Compared with the GMAW, the weld width reduce 0.4 mm and the weld penetration increased by 100% in the CU-GMAW, the weld width reduce 0.19 mm and the weld penetration increased by 67.7% in the PU-GMAW.

Key words: continuous ultrasonic; pulsed ultrasonic; GMAW; short circuiting transfer; weld appearance

Dynamic behavior of laser scanning welding pool and plasma HUANG Ruisheng[1], ZOU Jipeng[1], GONG Jianfeng[2], YANG Yicheng[1], LIANG Xiaomei[1] (1. Harbin Welding Institute Limited Company, Harbin, 150028, China; 2. State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin, 150001,China). pp 11-16

Abstract: With the material of aluminum alloy 5A06, the weld pool and plasma plume dynamic behavior during laser scanning welding were photographed by using high-speed photography. The character of fluidity for molten pool surface and of plasma plume vibration were analyzed under conventional single laser beam and laser scanning welding. The research results showed that compared with Single laser beam, the oscillating laser beam can greatly enhance the stability of plasma, prolong the cycle, increase the direction of the molten pool flow at the same time, and improve the stability. On the whole welding molten pool surface backflow phenomenon did not occur. Dynamic pressure resulting from molten pool flow reduced the impact of the keyhole. The keyhole stability is greatly improved.

Key words: laser scanning welding; molten pool; plasma plume; keyhole

Grain growth and phase transformation in the welded joint HAZ of TiNbV microalloyed steel FU Kuijun[1,2], ZHAO Jingwei[1], GAO Mingze[2], LENG Xuesong[1], YAN Jiuchun[1] (1. State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin, 150001, China; 2. State Key Laboratory of Metal Materials for Marine Equipment and Application, Anshan,114009, China). pp 17-22

Abstract: The grain growth and phase transformation in HAZ of TiNbV microalloyed steel under simulated welding