EH36钢厚板双面双弧打底焊焊缝组织及性能

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摘 要：EH36钢厚板广泛应用于造船行业，文中采用多层多道双面双弧机器人 MAG自动化立焊工艺焊接 EH36钢，具有显著的优点和广阔的应用前景．打底焊是多层多道焊接中最重要的工艺过程，对接头性能有着重要影响．文中对打底焊接头组织和性能进行了研究．结果表明，厚板双面双弧立焊打底接头组织主要为针状铁素体和先共析铁素体．在经历随后的多层多道焊再热作用后，打底焊缝组织得到细化．打底焊接头热影响区过热组织为贝氏体组织和板条马氏体组织．性能研究发现，打底焊焊缝的硬度值相比后层焊道要低．接头强度高于母材，断口形貌呈现韧窝特征．

关键词：打底焊；双面双弧；机器人立焊；焊缝组织
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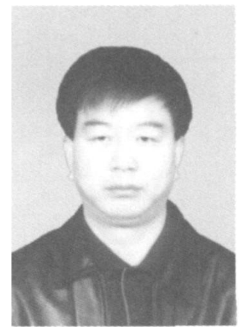

刘殿宝

0 序 言

EH36高强度钢厚板被应用于船体重要受力结构的建造中[1]．而传统 EH36厚板焊接大都采用手工电弧焊或半自动焊接．在设计和施工上都是选用非对称坡口，焊接时采取先焊接正面坡口、从反面碳弧气刨清根、刨槽、打磨、预热后再进行焊接的工艺．不仅容易产生焊接缺陷和焊接变形，而且焊接工序多，产品的质量稳定性差，生产效率低，工人劳动强度大，生产环境恶劣．

双面双弧焊（double-sided arc welding，DSAW）作为一种高效焊接的方法，电弧更集中，可有效提高焊接熔深及其深宽比，减少焊接变形，并消除焊接缺陷[2,3]．双面双弧焊接可以根据所使用的焊接电源的方式划分为两种类型：双电源型和单电源型．其中双电源型双面双弧焊接指的是在焊接过程中，两把焊枪采用两台焊接电源分别供电，实际上是焊缝两侧相互独立的焊接过程同时进行．对于双电源的双面双弧焊接，又可根据两电弧之间的相对位置，划分为非对称焊与对称焊[4]．对称焊，两焊枪电弧之间是完全在同一位置对称焊．非对称焊，则是两焊枪之间以一定的固定间距一前一后的焊接．双电源型双面电弧焊在实际工程应用较多[5,6]，但对于双面双弧焊接形成的的组织变化等机理研究较少．双面双弧工艺的主要局限性来源于双面焊对工件的可达性和双面焊接时两把焊枪的位置对准性[7]．对准准确性与焊缝轨迹所要求的准确性密切相关．而采用焊接机器人可大大减少这方面误差，提高精度和准确性．尤其是在多层多道焊接中，劳动强度大，焊接环境差，利用焊接机器人实施双面双弧焊接可提高焊接效率，减少劳动强度，改善焊接环境，具有很大的应用价值．

文中针对 EH36厚板实际焊接要求，采用焊接机器人实施多层多道的双面双弧的非对称立焊．多层多道焊中，打底焊是最关键的环节，它的焊接质量好坏直接决定整个焊接接头的性能．针对 50 mm厚 EH36钢利用焊接机器人在不预热的情况下进行了填丝多层焊工艺研究．在此基础上对打底焊接头的显微组织形态进行研究，测试了打底焊接头的硬度和拉伸性能，并分析了断口形态．

1 试验方法

试验材料为 50 mm厚 EH36高强钢，试件规格为 600 mm×120 mm×50 mm，开对称 X形坡口，坡口角度 60°，其化学成分见表 1．填充焊丝采用直径 1.2 mm焊丝，牌号为 ER50－6化学成分见表 2．

试验采用 KUKA机器人和 Transpuls synergic 4000型焊接电源，MOTOMAN焊接机器人和 MOTOWELD－S350型焊接电源．试验原理如图 1所

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表 1 EH36钢化学成分（质量分数,%）
Table 1 Chemical component of EH36 steel

C	Si	Mn	Cu	Al	Cr	Ni	Fe
0.15	0.606	1.45	0.193	0.125	0.221	0.223	余量

表 2 ER50-6焊丝成分（质量分数%）
Table 2 Chemical component of ER50-6 filler wire

C	Si	Mn	Ni	Mo	Ti	Fe
0.028	0.493	1.48	2.36	0.239	0.118	余量

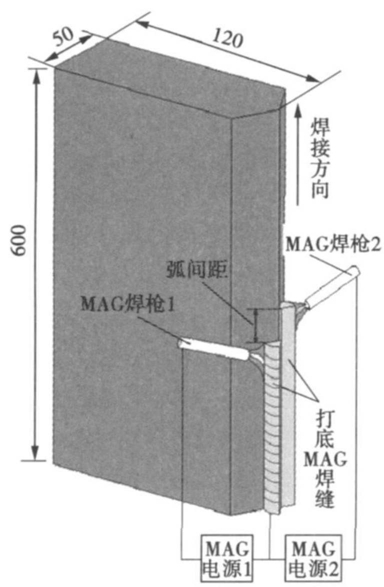


图 1 打底焊原理图（mm）
Fig. 1 Schematic diagram of backing weld

示,两把焊枪分别在工件两侧,两焊枪保持一定的弧间距,实现了双面双弧打底焊. 由于前后都有焊枪的保护气体对熔池保护,不易因氧化造成夹杂等缺陷,在两焊板之间留有根部间隙 2～3 mm,焊枪摆动施焊,能保证立焊时根部完全熔合好.

优化后的工艺参数为焊接电流 120 A,电弧电压 18 V,焊枪行走速度 1.25 mm/s,电弧摆幅为 3 mm. 两电弧采用相同的焊接工艺参数. 值得指出的是,在焊接试验研究中省去了焊前预热工序. 双弧双面焊试验后,制作焊接接头横截面的试块,经打磨后抛光腐蚀,采用光学显微镜及 S-570型扫描电子显微镜（SEM)观察分析焊缝组织及断口形貌.

2 试验结果和分析

2.1 打底焊焊接接头组织特征

图 2为 EH36钢双面双弧焊接接头的宏观形貌,通过上述的优化工艺参数基本消除了焊缝未熔合和气孔缺陷,成形良好. 图 3为焊缝部位及热影响区的组织形貌,可以观察到,焊缝与热影响区之间的熔合区非常明显. 焊缝两侧靠近熔合区部分为粗大柱状晶组织,越接近焊缝中心位置,柱状晶的形态明显变小.

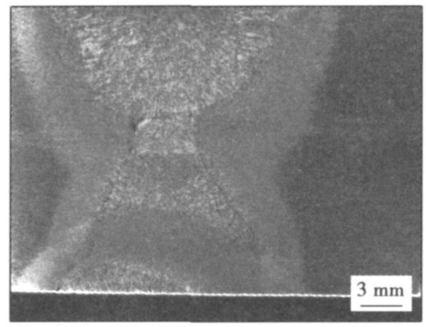


图 2 接头宏观形貌
Fig. 2 Macrograph of weld joint

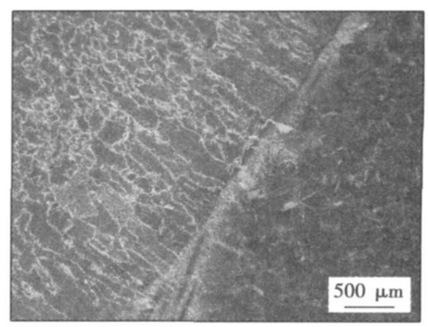
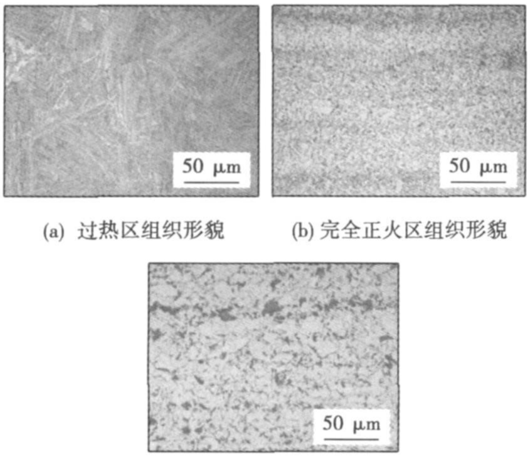


图 3 焊缝组织形貌
Fig. 3 Mirostructure of weld joint

图 4为打底焊母材热影响区不同区域的微观组织形貌. 过热区组织如图 4a所示,可以看出原奥氏体晶界清晰可见,主要由贝氏体类型组织和板条状马氏体组织组成,由于发生碳迁移及受到多重后热作用,其马氏体已不具有典型特征. 贝氏体类型组织的存在改善了过热区单一马氏体的硬度过高特点,提高了韧性.

图 4b所示的是完全正火区的组织,为细小的块状铁素体,在铁素体晶界处存在少量的珠光体类型的组织.

由图 4c可见,不完全正火区中焊前母材轧制状态仍然明显存在. 由于焊接时加热到两相区,一部分铁素体完全熔入到奥氏体中在随后的冷却过程中形成了珠光体. 决定了不完全正火区的组织由与母材晶粒尺寸相当的铁素体,及部分细小的铁素体和珠光体构成.

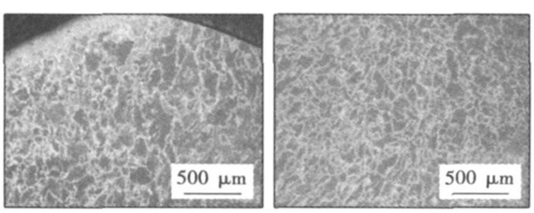


(a) 过热区组织形貌　(b) 完全正火区组织形貌

(c) 不完全正火组织形貌

图 4　热影响区组织形貌
Fig. 4　Microstructure of HAZ

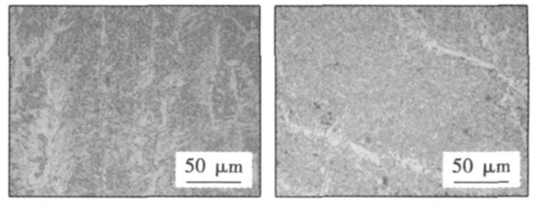
观察打底焊焊缝组织在经受后续焊道再热作用前后的形貌发现，这种再热作用并没有促使晶粒长大，反而使组织发生细化．图 5所示为填充后层焊道前后打底焊宏观组织形貌变化．未经历再热作用时，组织比较粗大，且不太均匀，填充后续焊道之后，组织状态得到改善，变得非常均匀细化，从而有利于改善焊缝力学性能．



(a) 未经再热作用的焊缝组织　(b)经历再热作用的焊缝组织

图 5　再热作用前后焊缝宏观组织
Fig. 5　Macrostructure of unreheating and reheating process

利用金相显微镜观察上述两种状态的打底焊焊缝微观组织发现，原始焊缝中白色区域为沿原奥氏体晶界析出的先共析铁素体，被这些先共析铁素体包围的是针状铁素体组织，在经历后续焊道再热作用之后，如图 6b所示，原焊缝组织中的先共析铁素体含量减少，针状铁素体含量增多．针状铁素体不仅能提高其强度，而且能显著提高其低温冲击韧度．针状铁素体比较细小，呈大角度晶界具有较强的抗裂纹扩展能力．针状铁素体含有高密度位错，微裂纹解理跨越针状铁素体要消耗较高的能量．因此使焊缝中出现足够数量的针状铁素体是提高强韧性的关键．



(a) 原始组织　(b) 多层焊后

图 6　多层焊再热过程后焊缝微观组织的变化
Fig. 6　Transformation of weld microstructure after reheating process of multi-layer welding

2.2　打底焊接头性能分析

如图 7所示，打底焊焊缝硬度要稍高于母材硬度值，大约在 220HV左右．焊缝两侧的热影响区硬度值明显高于母材和焊缝的硬度值，从不完全正火区经过完全正火区和过热区到熔合线附近，硬度值会突然增大很多，这主要是取决于在焊缝热影响区不同区域的组织构成不同．与不完全正火区以珠光体和铁素体为主不同，在完全正火区和过热区有贝氏体和马氏体组织的形成．马氏体和贝氏体组织的存在是导致硬度提高的直接因素．对比打底焊和第二层焊缝的硬度值，发现打底焊的硬度值整体偏低．分析认为，由于后焊道对打底焊的再热作用，相当于对打底进行回火处理，消除应力和成分偏析，使组织变得均匀，降低其淬硬倾向，提高了韧塑性．这对打底焊的性能和整个焊缝接头都有重要影响．

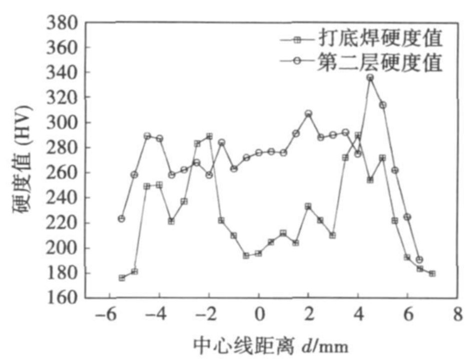


图 7　宏观硬度分布曲线
Fig. 7　Hardness distribution at weld joint

对打底焊获得的接头进行拉伸试验，发现断裂均发生在母材处，说明焊缝强度要高于母材．分析认为，这与焊丝成分组成对改善焊缝金属组织和性能的调节作用，打底焊时双弧的热作用及后焊道的回火作用都有很大的关系．如图 8所示对拉伸断口观察发现，断口为典型的韧窝形貌．

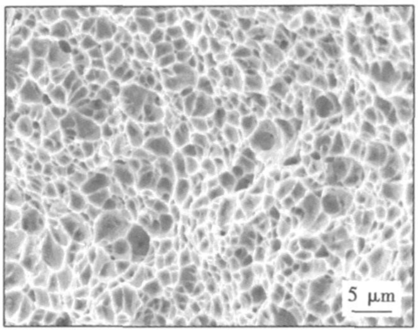


图 8 打底焊断口形貌
Fig. 8 Morphology of fracture surface of backing weld

3 结 论

(1) 利用机器人双面双弧 MAG焊打底,与传统工艺相比,减少了预热工序,提高了生产效率,改善了焊接环境.

(2) EH36钢双面双弧打底焊热影响区过热组织为贝氏体组织和板条马氏体组织,改善了单一马氏体的过硬性问题,在一定程度上改善了焊缝性能.

(3) EH36钢打底焊缝组织主要为先共析铁素体组织和针状铁素体组织,经历后层焊道的再热作用后,晶粒细化,先共析铁素体含量减少,针状铁素体含量增加.

(4) 打底焊缝硬度较母材高,在热影响区出现峰值,打底经再热作用后硬度有所降低但仍高于母材. 室温拉伸断裂发生在母材处,断口为典型的韧窝形貌.

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lege of Mechanical and Electrical Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China). p 73—76

Abstract: The Cu-Sn-Ti active filler alloy was utilized to braze CBN (cubic boron nitride) to steel substrate in vacuum furnace. The microstructure and the element distribution, as well as the topography and phases of the compounds were analyzed by optical microscopy, scanning electron microscope (SEM), energy dispersion spectrometer (EDS) and X-ray diffraction (XRD). The results show that the active element Ti migrated from the filler layer to the surface of the CBN grains to form the compounds such as TiN, TiB and TiB_2, which play an important role in the joining of CBN grain and Cu-Sn-Ti alloy. As a result, the layer of TiN+TiB+TiB_2-Cu/Sn/Ti intermetallic compound-Cu/Fe/Sn diffusion layer and Fe/Ti compound were formed between the interface of CBN and metal matrix.

Key words: vacuum brazing; Cu-Sn-Ti filler alloy; cubic boron nitride; microstructure

Special flash butt welding machine in cold rolling and pickling line WANG Rui, SUN Hexu, WANG Liwei, GAO Zhonglin (1. School of Control Science and Engineer, Hebei University of Technology, Tianjin 300130, China; 2. Tianjing 707 Hi-tech Company Limited, Tianjin 300409, China). p 77—80

Abstract: According to characteristic of cold rolling and pickling line, this article presents total configuration and control system of special flash butt welding machine in cold rolling and pickling line. The power system of special flash butt welding is analyzed, the mathematics model is built, its main circuit adopts single phase AC voltage controller. The flash process includes the former and the later. In the flash stage, output voltage is controlled by transformer tap and thyristor control angle is π. In the upset stage, output voltage is controlled by thyristor control angle. Running-in speed of upset hydraulic system is controlled by error between upset hydraulic cylinder actual value and the flash curve. Experiments showed that the flash welding machine met the requirements of strip billets welding.

Key words: cold rolling and pickling line; flash butt welding; power supply sistem; hyddraulic system

Microstructure and performance of backing weld joint of EH36 steel thick plate by double-sided arc welding LIU Dianbao[1,2], LI Fuquan[1], TAN Caiwang, CHEN Yanbin[1], ZHAO Yumei[2] (1. State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China; 2. Bohai Shipbuilding Heavy Industry Co. Ltd., Huludao, Liaoning 125004, China). p 81—84

Abstract: EH36 steel thick plate is widely used in shipbuilding industry. In this paper, double-sided arc welding (DSAW) vertical welding of EH36 steel is carried out by robots, which exhibits distinctive merits and broad prospective in application. Backing weld is the most significant procedure in the multi-layer and multi-pass welding, which exhibits important impact on weld joint. Microstructure and performance of back welding joint were studied. The results indicated that proeutectoid ferrite (PF) and acicular ferrite (AF) were the main structure in the weld joint after DSAW. The structure in the back weld was refined after reheating effect in the subsequent multi-layer and multi-pass welding. Microstructure at coarse-grained zone of backing weld joint was bainite and maetensite lath. The hardness of back weld was slightly lower than that of the second layer bead. Joint tensile strength was higher than that of base metal, and the characteristic of fracture appearance was dimple.

Key words: backing weld; double-side arc welding; robot vertical welding; microstructure of weld

Control of buckling distortion of TC4 thin plate by impact revolution pressing during welding process ZHANG Yong[1,2], YANG Jianguo[1], LI Jun[1], LIU Xuesong[1], FANG Hongyuan[1] (1. State Key Laboratory of Advanced Welding Technology Production, Harbin Institute of Technology, Harbin 150001, China; 2. School of Material Science and Engineering, Liaoning Technical University, Fuxin, Liaoning 123000, China). p 85—88

Abstract: The welded residual compression stress which is larger than the compression residual stress can cause buckling distortion of TC4 thin plate in normal welding process. In order to decrease the buckling distortion, the method of impact revolution pressing during welding was utilized to gain plastic extension in the certain temperature zone of the welding bead. The residual stress can be reduced by compensating the plastic shrinkage in the zone. The experiment results show that the deflection can be decreased to one eighth of the original deflection by impact revolution pressing. Higher input voltage, more the deflection can be reduced. The method of impact revolution pressing in welding process is feasible to control the deflection of TC4 thin plate weldment.

Key words: impact revolution pressing in welding process; TC4; buckling distortion; thin plate weldin

Methods of track fitting on big frame intersection line seam MIAO Xingang, WANG Su[1], LI Xiaohui[2] (1. School of Mechanical Engineering and Automation, Beijing University of Aeronautics and Astronautics, Beijing 100191, China; 2. Beijing Institute of Control Engineering, Beijing 100190, China). p 89—92

Abstract: There are some errors when big frame intersection line welded structural assemblies are produced, so the trace of seam is both instructed and fitted as the robot is used, in which quality of welding is decided by the precision of fitting. Focused on saddle-back welding seam, ellipse fitting and three-coordinate axis separated least square algorithm fitting are both designed. Simulation based on some teaching points in key position is made, and the result shows that the three-coordinate axis separated least square algorithm fitting is more precise than the ellipse fitting. It is more fitted for big intersection line welding frame.

Key words: intersection line; welding robot; ellipse fitting; least square fitting