

多层焊对 A/P 异种钢复合管 SMAW 接头组织及性能的影响

王能利¹, 张希艳¹, 潘希德², 薛 锦²

(1. 长春理工大学 材料科学与工程学院, 长春 130022;

2. 西安交通大学 材料科学与工程学院焊接研究所, 西安 710049)

摘 要: 不锈钢焊缝及熔合区组织对奥氏体(A)/珠光体(P)异种钢复合管焊接接头性能有重要影响。采用 E309L 型超低碳奥氏体不锈钢焊条的焊条电弧焊(SMAW, shielded metal arc welding)方法制备了 0Cr18Ni9/20 复合管单层焊和多层焊接头, 并应用光学金相、能谱(EDS, energy dispersive spectrum)成分及线扫描、扫描电镜(SEM, scanning electron microscope)、X 射线衍射以及显微硬度等方法对焊接接头进行了对比分析研究。结果表明, 基层焊缝的再热作用可以使不锈钢焊缝的 δ -Fe 相细化, 熔合区合金元素分布更加均匀, 且无 Cr_{23}C_6 相析出, 对接头性能产生有利影响。

关键词: 多层焊; 复合管; 超低碳奥氏体不锈钢焊条; 焊条电弧焊

中图分类号: TG444⁺.74 **文献标识码:** A **文章编号:** 0253-360X(2007)09-051-04



王能利

0 序 言

0Cr18Ni9 钢和 20 钢分别为常用的奥氏体不锈钢(A)和珠光体钢(P), 各自都有良好的焊接工艺性能, 而 0Cr18Ni9+20 钢复合板材及管材结合了不锈钢的耐腐蚀性能和普通碳素钢的高强度、低成本的性能特点, 广泛应用于动力装置、石油化工以及制药制碱等行业的设备中^[1], 特别是不锈钢覆层厚度在 0.5~1 mm 的复合管应用日益广泛。一般不锈钢复合管的覆层厚度都在 2~3 mm 以上, 而对于薄覆层 0Cr18Ni9/20 复合管, 由于不锈钢覆层太薄, 不能单独焊覆层, 焊接的第一层焊缝就是不锈钢焊缝, 然后焊基层焊缝。在焊接工艺上, 要保证不锈钢焊缝的单面焊双面成形, 在焊接过程中不产生冶金缺陷及工艺缺陷, 而且要保证焊缝的化学成分、金相组织, 特别是耐腐蚀性能与 0Cr18Ni9 覆层基本相同, 因此在焊接工艺上有一定的难度。理想焊缝组织为 γ +(4%~10%) δ 铁素体。 δ 铁素体含量太多时, 在高温下易转变为 σ 脆性相和 Cr_{23}C_6 碳化物, 降低焊缝的抗腐蚀和抗裂性能^[2]。而基层焊缝的加热作用对不锈钢焊缝组织的影响是值得关注的问题, 因为最终服役的管接头都是多层焊接头, 基层的再加热对

不锈钢的 δ 铁素体形状和含量、熔合区组织有何影响、是否有碳化物的析出等因素, 将影响焊接接头的性能。关于盖面层的再加热对奥氏体—珠光体钢异类焊接接头的影响存在不同的观点, 文献[3, 4]认为高焊接热输入的再热作用会导致碳迁移、 σ 相析出以及 HAZ 中晶粒粗化, 从而可能引起焊缝金属脆化和耐腐蚀性能下降。但文献[5, 6]也发现对于 Ni 基合金焊缝金属, 短时间的高温焊后热处理对接头的高温时效性能有利。作者制备了单层焊和多层焊的 0Cr18Ni9/20 复合管焊接接头, 对其焊缝和熔合区组织进行了对比研究, 以便为制定和优化该类复合管的焊接工艺进而促进其推广应用提供有价值的参考。

1 试验方法

对于 A/P 异种钢焊接, 在焊接工艺上应尽量减小焊接热输入和焊缝的熔合比, 应采取小电流、快速焊的方法, 焊接时层间温度应控制在 60℃以下。试验采用焊条电弧焊(SMAW)打底和盖面的焊接工艺对 0Cr18Ni9/20 复合管进行对接焊, 电源为直流反极性。打底焊(即不锈钢)焊材采用 E309L 型超低碳奥氏体不锈钢焊条 CHS 062, 基层选用与 20 钢材质相对应的 J427 低氢焊条。焊接接头形式如图 1 所

示,图 1b 为焊后的接头及检验部位。接头采用 V 形带钝边坡口,坡口角度为 $65^{\circ} \pm 2.5^{\circ}$,组对间隙为 $2.0 \text{ mm} \pm 0.5 \text{ mm}$,钝边高度 0.5 mm 。

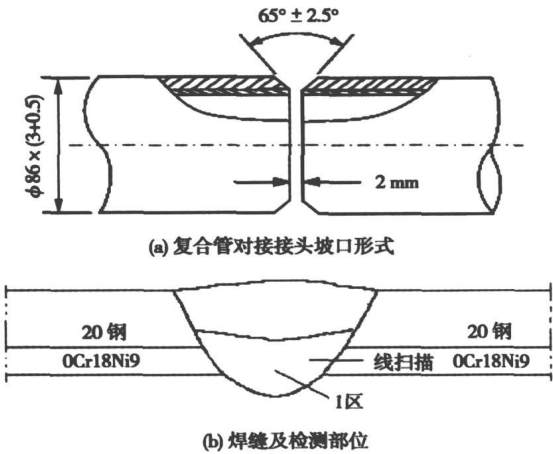


图 1 焊接接头形式
Fig 1 Feature of welded joint

试验采用的焊接工艺参数见表 1。按表 1 的工艺参数分别制备过渡层单层焊接头 and 多层焊接头,将接头磨制成金相试样,对不锈钢焊缝中心区(图 1b 中的 1 区)和熔合区(沿图 1b 中线扫描方向)进行光学金相、扫描电镜(SEM)、能谱(EDS)成分分析及线扫描、X 射线衍射以及显微硬度分析,以观察多层焊对接头性能的影响。试样采用 10% 草酸水溶液电解+4% 硝酸酒精溶液双重腐蚀。

表 1 SMAW 焊接工艺参数
Table 1 SMAW parameters

焊接材料	层数	焊接电流 I/A	电弧电压 U/V
CHS 062, Φ2.5	第 1 层	58—70	25—30
J427, Φ3.2	第 2 层	80—90	22—28

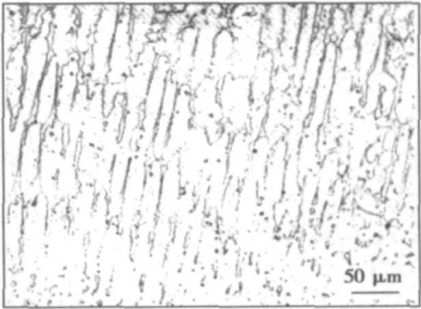
2 试验结果及分析

2.1 不锈钢焊缝金相组织及化学成分

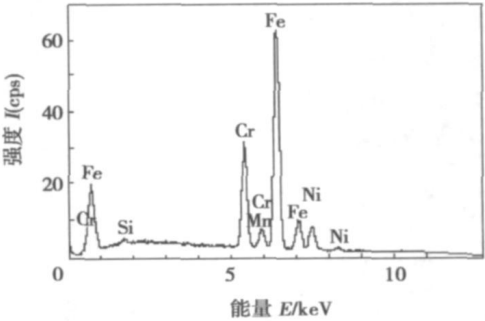
不锈钢焊缝(图 1b 中的 1 区)的金相组织及该组织所在区域的能谱成分分析结果见图 2。

从图 2 可见,不锈钢焊缝为 $\gamma + \delta$ 双相组织,单层焊的 δ 铁素体以蠕虫状为主,也有少量的骨架状和粒状 δ 相, δ 铁素体含量在 7%—9.5% 之间。而从图 2c 可见,经过基层焊缝的再热作用,不锈钢焊缝的 δ 铁素体由较粗大的蠕虫状变成以粒状 δ 铁素

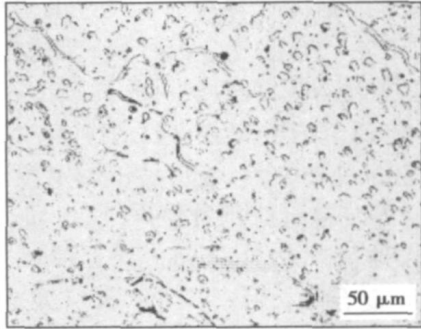
体为主,这说明多层焊接热循环对不锈钢层组织产生了影响。文献[7]研究了焊接层数对打底层中 δ -Fe 形态的影响,发现打底焊层的 δ -Fe 含量随焊接层数而变化,并呈球状分布。关于在热作用下 δ -Fe 向奥氏体或其他相的转变,文献[8]给出了如下的动力学公式,即



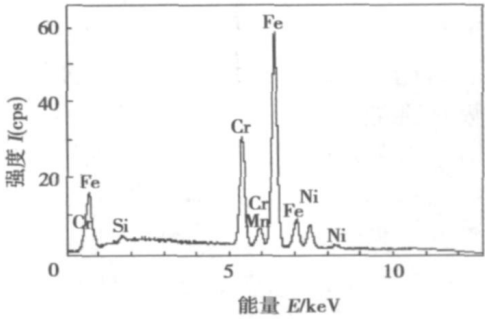
(a) 单层焊



(b) 单层焊EDS能谱面分析



(c) 多层焊



(d) 多层焊EDS能谱面分析

图 2 不锈钢焊缝的金相组织及能谱
Fig 2 Microstructure and EDS of stainless steel layer at weld

$\ln[-\ln(1-x)] = 19.32 - 19\,860/T + \ln t/2$,
式中: x 表示在温度 T 和时间 t 时的 δ -Fe 转变量。
从式中可以看出, T 是影响 x 的主要参数, t 的影响较小。在多层焊中, 基层焊接热循环的作用是非平衡和非均匀的, 它把不锈钢焊缝中由凝固形成的骨架状 δ -Fe 一次结晶组织破碎, 并发生 $\delta \rightarrow \gamma$ 的转变, 使 δ 铁素体细化为球形, 含量有所减少。这对焊缝的抗腐蚀和抗裂性能是有利的。

能谱分析表明, 单层焊和多层焊不锈钢层 Cr、Ni 含量基本相同, 分别为 18.71% 和 9.55% 左右, 说明再热作用对焊缝化学成分基本没有影响。不锈钢焊缝成分也与 1Cr18Ni9 母材基本一致, 表明焊缝和 0Cr18Ni9 母材处于同一电极电位区, 保证了焊缝具有与 0Cr18Ni9 母材相同的抗腐蚀性能。这说明基层的再热作用对不锈钢焊缝的金相组织是有利的。

对多层焊的不锈钢焊缝进行了 X 射线衍射分析, 结果见图 3。焊缝中只有 δ 和 γ 两个相, 没有发现 Cr_{23}C_6 相的析出。这是由于在焊接工艺上, 采用的是小电流, 短道焊和快速焊方法, 焊缝在敏化区域停留时间短, 使 C 来不及扩散; 且采用超低碳焊材, 使可用来扩散的 C 含量有限。这两个因素使焊缝中 Cr_{23}C_6 的含量很少, 确保了焊缝服役过程中不会有晶间腐蚀的发生。

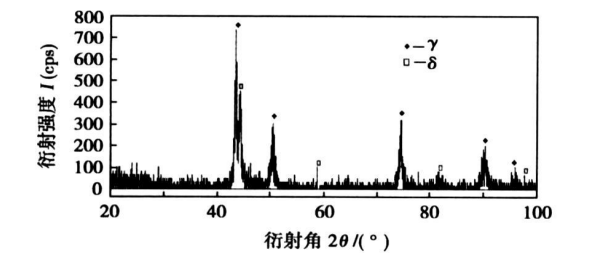
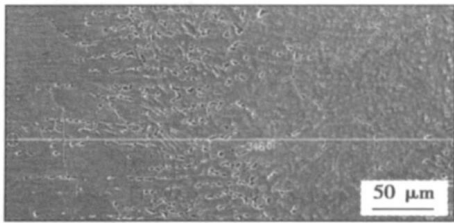


图 3 多层焊不锈钢焊缝的 X 射线衍射图
Fig. 3 XRD pattern of multi-passes welding

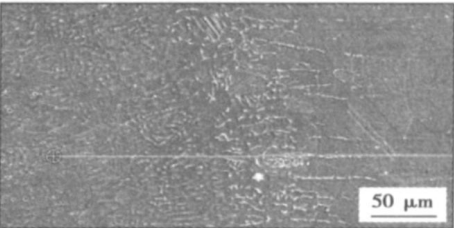
2.2 不锈钢接头的 EDS 线扫描分析

沿图 1b 所示的线扫描方向对单层焊和多层焊的不锈钢焊缝/0Cr18Ni9 界面进行能谱线扫描分析, 结果见图 4。

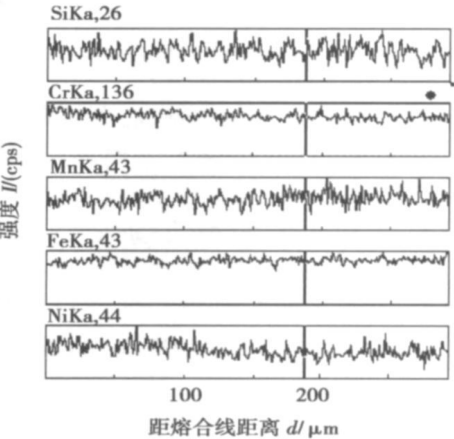
图 4 中的竖线是熔合线的位置, 由 SEM 图可见, 经过基层焊缝的再热作用, 多层焊不锈钢接头熔合区看不出明显的金相组织变化, 只是 δ 相相对细小些。熔合区组织中, 交互结晶区清晰可见, 母材和焊缝的奥氏体晶粒形态有所区别, 母材基本上是等轴晶, 焊缝是柱状晶。由 EDS 线扫描可见, 多层焊接头合金元素的浓度起伏较小, 分布比单层焊更为



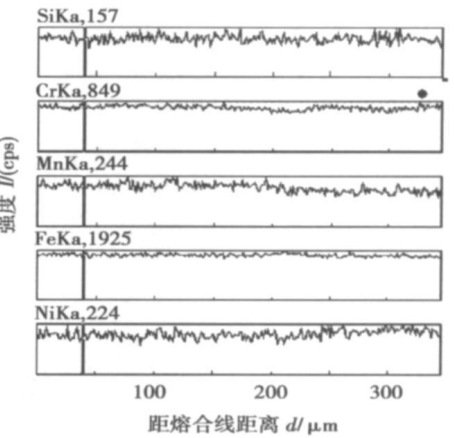
(a) 单层焊线扫描位置



(b) 多层焊线扫描位置



(c) 单层焊线扫描能谱



(d) 多层焊线扫描能谱

图 4 不锈钢焊缝/ 0Cr18Ni9 界面 EDS 线扫描
Fig. 4 EDS line scan of interface

平均, 和 0Cr18Ni9 母材基本一致。这是由于基层的再热作用增加了 δ/γ 相界面附近的空位浓度, 加速了 Cr、Mo 等合金元素的扩散能力, 使其发生了短程扩散^[9], 使不锈钢焊缝/0Cr18Ni9 界面合金元素分布趋于平均, 这对熔合区的组织性能是有利的。

2.3 不锈层接头显微硬度分析

材料的硬度值与其他静载荷下的力学性能存在一定关系, 为了判断多层焊对不锈层焊缝/0Cr18Ni9 接头熔合区组织性能的影响, 沿图 1b 线扫描方向进行显微硬度分析。显微硬度测量值为维氏硬度 HV, 载荷 0.98 N, 加载时间 5 s, 测量结果见图 5。

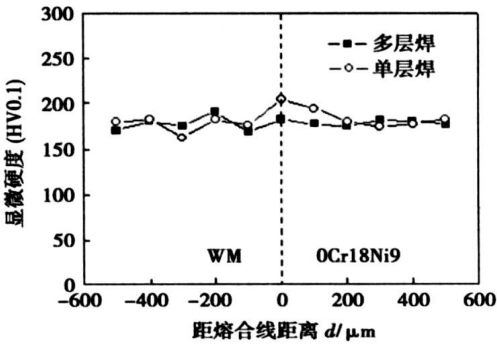


图 5 不锈层焊缝/0Cr18Ni9 界面显微硬度
Fig. 5 Microhardness on interface

从图 5 可见, 硬度值没有明显的峰值和谷值, 说明焊接过程中没有碳迁移现象及凝固过渡层的出现。基层焊缝的再热作用对远离熔合区的焊缝和 0Cr18Ni9 母材的硬度影响不大, 单层焊和多层焊的焊缝和 0Cr18Ni9 母材的硬度基本一致, 但靠近熔合区的单层焊不锈层焊缝的硬度比多层焊略高。这是由于焊缝的再热作用使 δ 铁素体细化、数量减少而引起的。在奥氏体不锈钢焊缝中, 随着 δ 相的增加, 焊缝的硬度是上升的^[10], 因此造成了再热后熔合区附近焊缝硬度的下降。从图 5 可以看出, 显微硬度的这种变化使焊接接头的硬度值趋于一致, 这也和金相组织及化学成分的变化趋势是一致的, 是有利于接头性能的变化。

3 结 论

(1) 采用表 1 所示的工艺参数, 对 0Cr18Ni9/20 复合管进行对接焊, 不锈层焊材采用 E309L 型超低碳奥氏体不锈钢焊条, 可获得组织性能良好的焊缝及熔合区组织。不锈层焊缝为 $\gamma + \delta$ 双相组织, 焊缝

的化学成分与 0Cr18Ni9 母材基本一致。

(2) 金相及 XRD 分析表明, 多层焊的再加热作用使不锈层焊缝较粗大的蠕虫状 δ 铁素体结晶组织破碎, 并发生 $\delta \rightarrow \gamma$ 的转变, 使 δ 铁素体细化为球形, 含量有所减少。再加热后不锈层焊缝中没有 $Cr_{23}C_6$ 相的析出, 对焊缝的抗腐蚀和抗裂性能有利。

(3) 能谱 (EDS) 及显微硬度分析表明, 多层焊的再热作用使过渡层焊缝/0Cr18Ni9 界面合金元素分布趋于平均, 没有碳迁移现象及凝固过渡层的出现, 而且使焊接接头的硬度值趋于一致。

参考文献:

[1] 张其枢, 堵耀庭. 不锈钢焊接[M]. 北京: 机械工业出版社, 2004.

[2] 中国机械工程学会焊接学会. 焊接手册(第 2 卷)[M]. 第 2 版. 北京: 机械工业出版社, 2004.

[3] Lundin C D. Dissimilar metal welds transition joints literature review [J]. Welding Journal, 1982, 61(2): 58—63.

[4] Karlsson L. Welding of dissimilar metal[J]. Welding in the World, 1995, 36(6): 125—132.

[5] Nicholson R D. Effect of post-weld heat treatment on development of interfacial structures in nickel-based transition joint[J]. Materials Science and Technology, 1985, 1(3): 227—233.

[6] Bhaduri A K, Venkadesan S. Combined effects of post-weld heat treatment and aging on alloy 800/ 2. 25Cr—1Mo steel joint[J]. Materials Science and Technology, 1991, 7(11): 1051—1056.

[7] Gowriankar I, Bhaduri A K. Effect of the number of passes on the structure and properties of submerged arc welds of AISI type 316L stainless steel[J]. Welding Journal, 1987, 66(5): 147—154.

[8] Thomas R G, Yapp D. The effect of heat treatment on type 316 stainless steel weld metal[J]. Welding Journal, 1978, 57(12): 361—366.

[9] 潘春旭. 异种钢及异种金属焊接[M]. 北京: 人民交通出版社, 2000.

[10] Zamelzu E, Hama M. Influence of microstructure on the mechanical behaviour of welded 316L SS joints[J]. Journal of Materials Processing Technology, 1999, 94: 37—38.

作者简介: 王能利, 男, 1967 年出生, 博士研究生。主要从事材料学、材料加工、焊接冶金方面的教学和科研工作。发表论文 10 余篇。
Email: wang_nengli@sina.com

es on A— TIG welding of magnesium alloy MA Xiang^{1,2}, ZHANG Zhaodong¹, LIU Liming¹, LIU Jinghe²(1. State Key Laboratory of Materials Modification & School of Materials Science and Engineering, Dalian University of Science and Engineering, Dalian 116024, China; 2. The Ministry of Education Research Center of Photo-Electricity Information Transmit of Materials & School of Materials Science and Engineering, Changchun University of Science and Technology, Changchun 130022, China). p39— 42

Abstract: For AZ31B magnesium alloy materials five kinds of single oxides MgO, Cr₂O₃, CaO, TiO₂, MnO₂ were used as the activating fluxes. The welding penetration, microstructures, phase composition and mechanical properties of welded joints without and with single oxide TiO₂ and the composite oxide were compared. The results of experiments showed that welding penetration of compound fluxes is 2.5 times than conventional tungsten inert-gas welding, also deeper than that with single flux. The crystal grain of the composite fluxes is smaller than that of single TiO₂ flux, and the tensile strength of the composite fluxes sample is superior to single TiO₂ flux sample. The activating element was added into weld that improve the phase composition of compound fluxes, which avoid the formation of the low-melting point magnesium-aluminum phase in the welded joint.

Key words: magnesium alloy; activating fluxes; unifom design method

Instantaneous short circuit in short circuiting transfer process in GMAW WANG Guangwei; CAI Yan; HUA Xueming; WU Yixiong (School of Materials Science and Engineering, Shanghai Jiaotong University; Shanghai 200030; China). p43 — 46, 102

Abstract: The critical condition of dynamic force equilibrium of instantaneous short circuit (ISC) in GMAW(gas metal arc welding) based on droplet pressure, electromagnetic force, and surface tension was presented while the dynamic force was analyzed. Based on micro focus high speed photography technique and digital image processing technology, the data of the droplet radius were obtained. And the electric signal was combined and analyzed. The results showed the short circuiting process reflects by the calculated data completely agreed with that from the images. The critical condition is proved. Further, the influence of the droplet shape on the ISC was analyzed based on this critical condition. If the radial radius was less than axial radius when the droplet touched with the wolten pool, the radial surface tension would be positive. The ISC stantes and can not be reversed, which means the spindly droplet leads to ISC frequently. Lastly, the ISC phenomena was classified and studied quantitatively. And the new explanation of ISC was proposed.

Key words: dynamic force equilibrium; instantaneous short circuit; gas metal arc welding

Dynamic monitoring of weld pod image for pulsed GTAW in welding scene WANG Zhijiang, ZHANG Guangjun, GAO

Hongming, WU Lin (National Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China). p47— 50

Abstract Information on stability and continuity of welding process can be obtained by dynamic monitoring of weld pool. The dynamic monitoring of weld pool is still in laboratory stage. To monitor weld pool in the welding scene is more valuable in both welding process improvement and production guide. However, there are some problems in welding scene, for example, the welding power sources cannot be modified and incontrollable by personal computer; the waveforms of welding current and voltage are unknown and so on. For these problems, a weld pool image dynamic monitoring system was setup in the welding scene. According to the characteristics of pulsed GTAW(gas tungsten arc welding) in the welding scene, the time to take image, which is the most important factor to restrict to take image in the welding scene, is determined by external synchronization; using the spectral analysis, a compound filter system, which reduces the interference of arc, was proposed; at the optimum image taking hour, clear images of weld pool were obtained by CCD with the compound filter system in the welding scene.

Key words: weld pool; visual monitoring; pulsed gas tungsten arc welding; welding scene; spectral analysis

Effect of multi-passes welding on microstructure and properties of austenitic/ pearlitic dissimilar steel clad pipe SMAW welded joint WANG Nengli¹, ZHANG Xiyun¹, PAN Xide², XUE Jin² (1. School of Materials Science & Engineering, Changchun University of Science and Technology, Changchun 130022, China; 2. School of Materials Science & Engineering, Xi'an Jiaotong University, Xi'an 710049, China). p51— 54

Abstract Microstructures of transition weld and melted zone has the important effects on properties of austenitic/ pearlitic dissimilar steel clad pipe welded joint. Single-pass and multi-passes welded joints of 0Cr18Ni9/20 clad pipe were prepared by the use of shielded metal arc welding (SMAW) and E309L super-low carbon austenitic stainless steel electrode. Studies on the welded joint were made by means of optical metaloscopy, energy dispersive spectrum, scanning electron microscope, X-ray diffraction and microhardness analysis. The results indicated that re-heating of cover pass weld can decrease the size and the content of δ -ferrite in transition weld, and the morphology of δ -ferrite in transition weld turns from the vermicular type to the granular type. The chemical compositions of melted zone between transition weld and 0Cr18Ni9 base metal become more uniform. And there was no precipitation of Cr₂₃C₆ carbides in transition weld after re-heating.

Key words: multi-passes welding; clad pipe; super-low carbon austenitic stainless steel electrode; shielded metal arc welding

Control model and software flow of main circuit for 3— phase low frequency welder MA Tiejun, ZHANG Yong, LI Jinglong,