基于 VRML 的焊接有限元分析前处理开发

高嘉爽[1], 杨建国[1], 方洪渊[1], 石文勇[2], 尚海波[3]
(1. 哈尔滨工业大学 现代焊接生产技术国家重点实验室, 哈尔滨 150001;
2. 哈尔滨理工大学 工程训练中心, 哈尔滨 150080; 3. 上海合晶硅材料有限公司, 上海 201600)

摘 要: 为减小焊接变形, 对复杂焊接结构要进行焊接顺序优化。文中使用虚拟现实建模语言(VRML)建立焊接模型, 用户通过简单操作来定义焊接顺序, 利用 script 节点将操作过程写入有限元分析软件 Marc 的过程文件中, 按照此焊接顺序进行有限元分析。该系统的开发将乏味、复杂的有限元前处理替换为逼真的虚拟世界操作, 为更好地确定焊接顺序、了解复杂焊接结构、焊接预装配等过程提供了解决方案。结合某产品油箱焊接结构的实例, 尝试与讨论了虚拟现实与有限元软件的集成, 这对于培训工人上岗、焊接质量分析等方面具有现实意义。

关键词: 虚拟现实建模语言; 焊接顺序; 有限元分析
中图分类号: TG404 文献标识码: A 文章编号: 0253-360X(2008)04-0093-04


高嘉爽

0 序 言

随着焊接技术的不断提高, 许多复杂零部件要求焊接成型, 这对提高焊接生产效率和批量焊接产品的质量指标提出了更高的要求[1]。有限元分析方法可以对产品结构进行静力分析、动力分析, 而在焊接之前进行应力、应变和温度的预测可以大大提高对焊接质量的控制水平, 并可优化焊接工艺参数, 提高焊接结构设计效率。目前有限元软件越来越多地应用于焊接分析。然而目前的有限元分析软件专业性不强。另外, 有限元计算软件一般都是从欧美等西方发达国家引进, 为通用软件, 并不是针对特定领域设计, 且操作极其复杂, 界面繁琐, 从而限制了数值模拟技术在企业中的广泛应用。同时, 这些软件再进行复杂焊接结构分析时, 缺乏直观的效果和良好的人机交互能力。

虚拟现实(virtual reality)是一种新兴的人机交互技术, 是计算机技术高度发展的产物, 凭借虚拟现实技术, 用户可进入一个由计算机模拟的虚拟世界, 并通过一些专门的装置来对场景进行具有真实感觉(视觉、听觉、触觉等)的交互操作, 从而能真切地感受到虚拟场景的存在[2]。

将虚拟现实技术应用于焊接技术, 可以更好地显示复杂的焊接变化过程, 目前的研究主要集中于针对工人上岗的虚拟训练方面[3]。文中针对焊接过程有限元分析, 提出将虚拟现实技术应用于前处理过程, 实现焊接模型的预装配。操作者与虚拟环境中的焊接件发生交互作用, 在计算机产生的三维仿真环境中, 安排合理的焊接顺序, 然后进行有限元分析。此过程有助于更好的感受虚拟环境中复杂的焊接结构, 直观地理解焊接顺序对焊接质量的影响, 为焊接顺序和焊接预装配等过程提供更好的解决方案, 为培训焊接人员, 分析焊接有限元计算结果和质量评价提供了有效途径, 可用于生产实践。

VRML(virtual reality modeling language)是以浏览器为支持平台的虚拟现实建模语言。文中以某产品油箱焊接结构为例, 利用 VRML 来实现产品的基于有限元分析的虚拟焊接预装配。

1 VRML 概述

VRML 是一种建模语言, 1998 年 1 月被正式批准为国际标准, 可用于描述三维物体及其行为, 构建虚拟境界。基本特点为分布式、三维、交互性、多媒体集成和境界逼真性等。

VRML 基于 open inventor 文件格式, 但未提供应用程序接口。与 HTML(hyper text markup language, 超文本标记语言)一样, VRML 使用 ASCII(american standard code for information interchange, 美国信息交换标准码)文本格式描述境界和链接。虚拟境界用场景图描述, 场景图的基本单元称为节点。节点由层次关系组合在一起, 节点之间可以通过事件相互通

收稿日期: 2007-05-18

信,事件通过路由在场景图中传播。检测器节点能检测用户动作或时间推移,从而产生初始事件,此为交互性和动态行为的基础。通过脚本节点,可集成用 java 或 javascript 语言写的程序代码,从而编写各种自定义行为。常用的基本动态行为可用插补器节点进行插值计算。插补器实际上是内置脚本,原型为一种类封装机制,利用它可在已定义节点类型的基础上定义新的节点类型,通过外部原型还可以跨越因特网引用自定义的节点类型。内联节点提供了场景之间的链接,从而形成跨越因特网的分布式三维多媒体[4]。

2 基于 VRML 的焊接有限元前处理分析系统

对于焊接有限元的前处理过程,建立焊接构建的三维模型,在虚拟环境中完成预装配,提交焊接加工的有限元计算软件,进行焊接分析。图 1 为模型在 VRML 浏览的执行流程图。

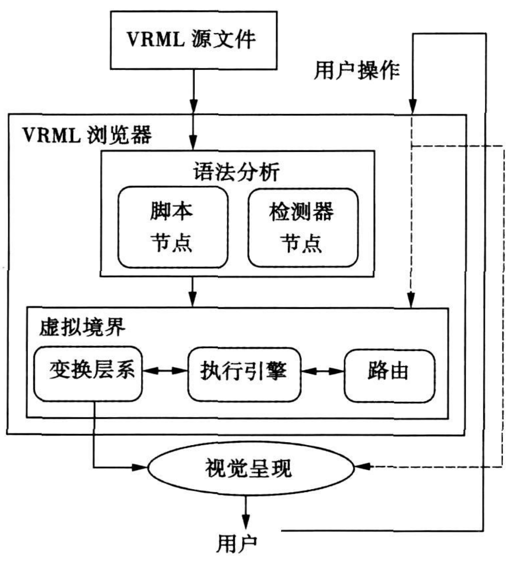


图 1 VRML 浏览器执行流程图

Fig. 1 Flow diagram of VRML explore

3 某油箱焊接构件的建模

油箱体积大,结构复杂,要实现虚拟装配必须先对基本构件建模。因很多构件形状特殊,难以直接用 VRML 语法编写程序。UG 建模软件可将生成的三维模型输出为 VRML(*.wrl)文件格式。利用 UG 制作构件模型较为直观,但生成的 VRML 文件过大,造成网上浏览的困难。为减小文件,可采取一些方法:手工修改,构件模型的 VRML 文件生成后,用 VRML 编辑器打开进行修改,在不影响精度和效果的前提下,用 VRML4 种基本形状来替代近似的面造型,还可用近似形状粘贴纹理的方法来达到模型的逼真效果;用 VRML pad 压缩,VRML pad 是专门用于编写 VRML 文件的编辑器,可以打包 VRML 文件,去除多余文件格式和缺省的域值,简化浮点数,其压缩率极高。但经过压缩的文件适合网络传播,而不适合编辑查看,故压缩需要在 VRML 文件编辑完成后进行[5]。

油箱各个零件的 VRML 文件(*.wrl)生成以后,要生成虚拟环境下的焊接预装配体,可以用 InLine 节点参数在合适的位置、方位来调用各个零件,重新组装成装配体,参考 UG 装配模型的尺寸,利用 transform 节点的 translation, rotation, scale 语句实现对油箱结构建模局部坐标的平移、旋转、缩放,从而保证在 VRML 环境中组装出油箱模型。由于每个零件的内容均在单独的文件内,主程序只用一行 InLine 参数表示,因而程序内容得以大大减少。

4 某油箱预装配与有限元分析实现

4.1 油箱焊接结构预装配的实现

利用 VRML 实现机构运动仿真实质上是依靠一个给定的时间传感器 timesensor、各种各样的插补器节点和 ROUTE 语句来实现的关键帧动画。文中采用方位插补器和位置插补器控制油箱虚拟焊接预装配的路径,从而实现其动态焊接仿真的过程。通过鼠标点击各个零件的顺序确定焊接顺序。

通过 route 语句实现零件移动路径与用户动作之间的交互效果。下面为实现语句,part1 代表油箱上需要的某块立板名称;touch1 代表鼠标接触动作;position1 代表位置插补器名称;time1 代表 part1 的时间触发器;

```
ROUTE:
touch1.touchTime TO time1.startTime
ROUTE:
time1.fraction_changed TO position1.set_fraction
ROUTE:
position1.value_changed TO part1.translation
```

实现的路由图如图 2。

4.2 虚拟焊接顺序的规划

进行焊接之前首先要确定焊接的顺序,在虚拟现实的环境,通过规划焊接顺序以达到最佳焊接质量。如图 3 为四块立板与壁板的油箱焊接结构。立板与盖板通过焊接连接;立板与壁板也通过焊接连

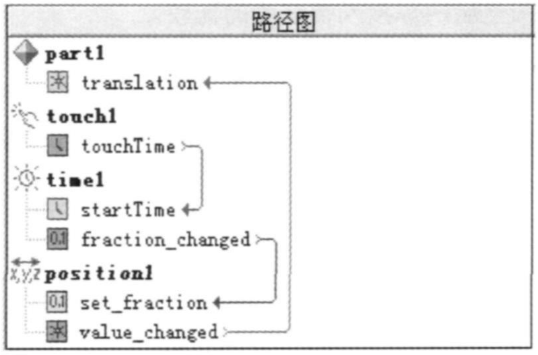


图 2　油箱某零件焊接顺序设计系统路由图

Fig 2　Route diagram of welding sequence for oil box

接。以壁板的焊接为例，对四块立板设计了以下五种焊接顺序组合(图 4)：1—2—3—4；1—3—2—4；1—4—3—2；对称 1—3—2—4；对称 1—4—3—2，其中数字先后顺序代表了各立板的焊接先后顺序。

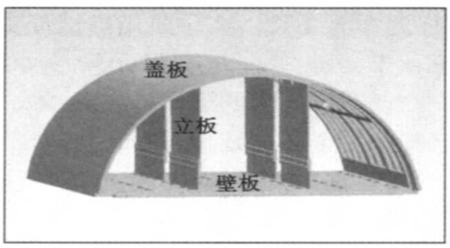


图 3　某油箱焊接结构

Fig. 3　Model of oil box

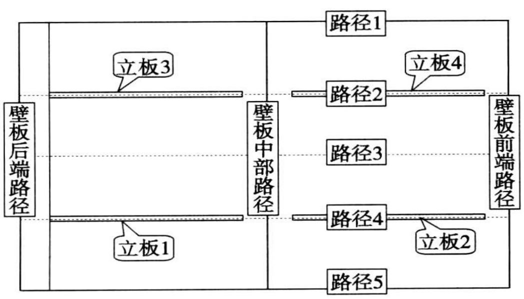


图 4　油箱焊接顺序示意图

Fig 4　Welding sequence of oil box

4.3　VRML 与有限元前处理的通讯实现

VRML 中的 script 节点可以描述由用户自定义制作的动作。实际上脚本节点是 VRML 与外部编程语言的接口，对一些需要在虚拟场景中实现的复杂行为都可以通过该节点使用 java 或 ECMAscript (即 javascript)编程实现。脚本节点接受到输入事件时，会通过域值 url 找到指定的脚本，对事件进行处理。文中采用 java 作为脚本语言。为实现 VRML 世界中的用户动作与有限元软件通讯的目的，在 java 程序中加入代码，根据鼠标动作修改有限元前处理过程文件(proc 文件)，从而达到与有限元计算软件通讯的目的。图 5 为通讯实现框图。

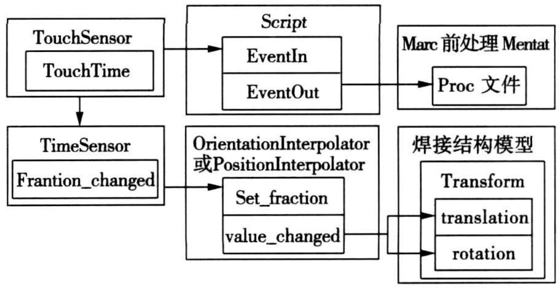


图 5　VRML 与有限元前处理的通讯实现框图

Fig 5　Diagram of VRML' s communication with Marc preprocess system

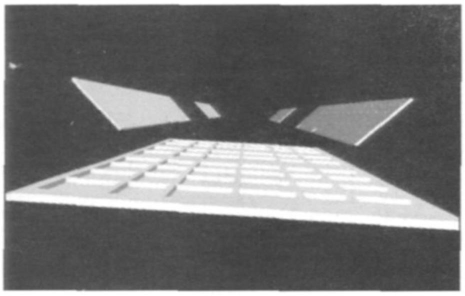
点击某块立板，启动接触传感器，向脚本中输入事件，Java 代码中加入对输入事件处理，包括记录下点击的立板号码，修改结果提交给 Marc 有限元软件的过程文件(proc 文件)。按不同的顺序实现预装配之后，在 proc 文件中就记录着操作者希望的焊接顺序，然后提交给 Marc 求解器，即可以开始计算。以下为修改 proc 文件的 java 代码片断。

```
import　java.io.*;
import　java.nio.*;
import　java.nio.channels.FileChannel;
String　s=“”;
　\定义字符串变量
String　p=“”;
　\定义字符串变量
BufferedReader　in=new BufferedReader(new FileReader(“e:/weldansys.dat”)); \定义
BufferedReader 类的对象
　while((s=in.readLine())! =null)
\读取 proc 文件的文本形式文件
{修改 proc 内容;}
FileOutputStream　output=null;
\定义 FileOutputStream 类的对象
File　file=new　File(“c:/new weld.proc”);
\写入文件
……
```

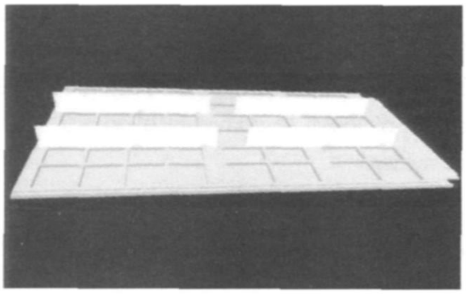
4.4　油箱焊接顺序 VRML 实现与有限元计算结果

编制完 VRML 程序之后，采用浏览器插件 Cortona 看到效果，并且与构件进行交互，实现焊接预装

配的仿真。图 6 为壁板结构未焊接之前的各个零件与按一定顺序点选之后的焊接预装配图的比较。图 7 为盖板结构未焊接之前的各个零件与按一定顺序点选之后的焊接预装配图的比较。

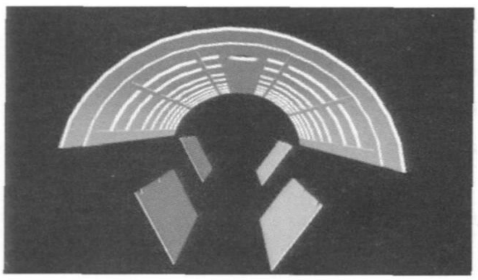


(a) 焊接前

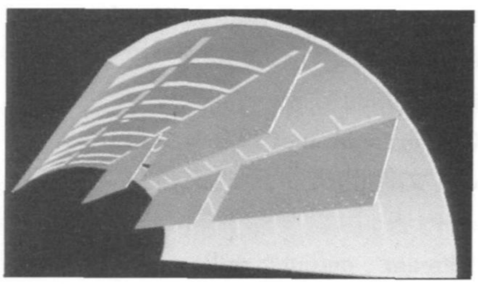


(b) 焊接预装配

图 6 油箱壁板模型
Fig. 6 Model of oil box' s wall



(a) 焊接前



(b) 焊接预装配

图 7 油箱盖板模型
Fig. 7 Models of oil box' s cover board

通过 script 节点的处理, 相应的动作被提交到 Marc 有限元前处理系统, 施加计算所需其它条件如: 边界载荷、初始温度、工况加载等之后, 开始求解。

5 结 论

(1) 以虚拟现实语言建立油箱焊接结构模型, 通过此语言中的时间传感器、接触传感器以及位置插补器等节点实现焊接结构的预装配, 通过编写路由图, 用户可以通过简单的鼠标操作完成焊接顺序的制定, 形象逼真地展示焊接过程, 同时方便了用户输入, 尤其对于复杂结构更能显示其优越性。而对于不需要进行焊接预装配的结构来说, 此种方法也可以通过用户的交互来实现焊接顺序的定义。

(2) 在有限元软件中, 采用工况载荷的形式添加焊接顺序的边界条件。文中采用虚拟现实建模语言中的 script 节点来实现与有限元软件 Marc 的通信, 使用户在虚拟世界中的操作传递到 Marc 前处理中, 省去乏味和复杂的前处理过程, 将抽象的条件加载转化为逼真地虚拟焊接操作, 为虚拟焊接制造系统的实现提供了思路。

参考文献:

[1] 孔 谅, 吴毅雄, 陆 皓, 等. 虚拟焊接制造系统集成仿真方法[J]. 焊接学报, 2005, 26(11): 69-74.

[2] 任继文, 龙 铭. 基于 VRML 的减速箱虚拟装配的实现[J]. 工艺与装备, 2004(4): 88-90.

[3] Mavrikios D, Karabatsou V, Fragos D, *et al*. A prototype virtual reality-based demonstrator for immersive and interactive simulation of welding processes[J]. International Journal of Computer Integrated Manufacturing. 2006, 19(3): 294-300.

[4] 韦素媛, 宁 超, 张世英, 等. 基于 VRML 的航天模拟训练系统[J]. 上海航天, 2003(1): 31-34.

[5] 宁 超, 张世英, 韦素媛. VRML 在航天仿真技术中的应用[J]. 计算机应用, 2002, 22(12): 126-128.

作者简介: 高嘉爽, 女, 1981 年出生, 博士研究生。主要从事虚拟焊接开发与有限元模拟方向研究。发表论文 4 篇。

Email: gaojiashuang2005@sohu.com.cn

Abstract: It is the key issue for the seam tracking to obtain the high quality images which are convenient to be processed in arc welding process shielded by the gas of CO_2. Firstly, on the basis of the principle that reflectors with curved surface reflect arc, a structure with the paraboloid of the reflecting mirror was constructed on the welding torch of the robot. The structure can produce parallel light by dint of arc which irradiates the area monitored by the CCD camera. The lum of the area is limited to the extent that is adapt to the camera. Secondly, the usability of the obtained images was discussed according to the characteristics of the welding process of short-circuit transfer and the directions of splash. Based on the algorithm of robot difference-moving, the obtained images were processed. The result of experiments has proved the validity of the method.

Key words: arc light reflecting; seam tracking; arc welding robot; image processing

Effect of welding wire compositions on microstructures and mechanical properties of welded joint of 2519 aluminum alloy

LI Huizhong[1,2], GUO Feifei[1], LIANG Xiaopeng[1], LI Zhou[1] (1. School of Materials Science and Engineering, Central South University, Changsha 410083, China; 2. School of Metallurgy Science and Engineering, Central South University, Changsha 410083, China). p77—81

Abstract: 2519 aluminum alloy was welded using ER4047 and ER2319 welding wire with the method of MIG welding. Mechanical properties and microstructures of welded joint were studied. The results show that the weldability of the 2519 aluminum alloy with ER2319 welding wire is better than that with ER4047 welding wire; the microstructures of weld metal is more refined with ER2319 welding wire than that with ER4047; The mechanical properties of welded joint is worse than that of base metal, the weld zone is the weakest point of welded joint. The soften zone in heat-affected zone (HAZ) is the second weakest zone of welded joint, which is formed due to the overaging of the main strengthening phase particles leading to coarsening.

Key words: 2519 aluminum alloy; composition of welding wire; mechanical properties; microstructure

Automatic control of open arc surfacing system for the milling roller

LI Zhenying, DAI Liping, HOU Ming, HE Qiong (College of Mechanical Electrical Engineering, Beijing Information Science & Technology University, Beijing 100192, China). p82—84

Abstract: The automatic control method of open arc surfacing welding system was studied for the milling roller. The moving system formula was built according to the mechanical structure of the open arc surfacing welding system. The surfacing welding process could be divided into same-arc section and transition-arc section according to its characteristics. Fitting the sunk milling roller as a spherical surface, a moving-track control method was raised and the moving control formulas for the same-arc section and the transition-arc section were derived. The error formula was also built. The error analysis gained with the aid of MATLAB proves the formulas and it meets the technical requirements.

Key words: milling roller; open arc surfacing welding; automatic control

Analysis of structure and growth of QCr0.8/TC4 welded reaction layer by electron beam welding

LIU Wei, CHEN Guoqing, ZHANG Binggang, FENG Jicai (State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China). p85—88

Abstract: QCr0.8/TC4 electron beam welding seam was composed of fusion zone and reaction layer, and the structure, phase composition and extent of reaction played important part in the joint tensile strength. According to the Fick diffusion law, the ratio of elements Cu and Ti diffusion flux can be calculated. In the reaction layer, CuTi was generated firstly, which was continuous and distributed in the reaction layer. The energy spectrum analysis indicated that the reaction layer composition was Cu+ Cu_xTi zone and CuTi based solid solution zone. And Cu_xTi was the mixture of several compounds, such as Cu_4Ti, Cu_3Ti, and Cu_2Ti and so on. Due to the rapid cooling, The zone near TC4 fusion line couldn't generate the second phase compound in the weld. Therefore, the continuous intermetallic compound CuTi rusulted in high residual stress and hard brittle layer, which was the main factor effecting the joint mechanical properties.

Key words: QCr0.8 alloy; TC4 alloy; electron beam welding; weld reaction layer

Equipment modeling of off-line programming system of the arc welding robot based on UG

FENG Shengqiang, HU Shengsun, DU Naicheng (School of Materials Science and Engineering, Tianjin University, Tianjin 300072, China). p89—92

Abstract: The modeling could contact the solid model of the robot with its modeling data, which made these solids identified by the off-line programming system, in the off-line programming system of the arc welding robot by the second development. The model was the base of the whole off-line programming system. In the surrounding of UGNX4.0, the equipment modeling of arc welding robot consists of three key module including part motion module, assemble modeling module and motion module. In the three of module, the part module is the base of them, and then the assemble modeling module and the motion module were taken. The models of the arc welding robot and positioner were successfully founded, which grounded the second development in the ground of UG and by using VC++ as the tool of the second development.

Key words: arc welding robot; off-line programming; modeling; second development

FEA preprocessing system of welding analysis based on VRML

GAO Jiashuang[1], YANG Jianguo[1], FANG Hongyuan[1], SHI Wenyong[2], SHANG Haibo[3] (1. State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China; 2. Engineering Training Center, Harbin University of Science and Technology, Harbin 150080, China; 3. Shanghai Wafer Works Corp., Shanghai 201600, China). p93—96

Abstract: In order to decrease welding deformation, welding sequence of complex welding structures need to be optimized. Welding model of these type structures has been developed with the virtual reality modeling language (VRML). Welding sequence was defined based on user's simple operation and written into procedure file of FEA software Marc's preprocessing system by script node. By this method, a vivid and interactive welding environment can replace the stuffy and complex processing analysis. It not only provides good guidance to understand complex welding structure and welding pre-assembly, but also discusses virtual reality and FEA software integration. It also supports welding quality analysis and training welding worker.

Key words: VRML; welding sequence; FEA

Finite element analysis on laser welding of aluminum alloy
ZHU Miaofeng, LU Fenggui, CHEN Yunxia, YAO Shun (Laser processing Laboratory, Shanghai JiaoTong University, Shanghai 200240, China). p97—100

Abstract: Based on the specific laser welding process of aluminum alloy, two kinds of heat sources were used in this calculation which could reflect effect of laser plasma and laser beam during laser welding process. The formation and development of keyhole has been analyzed by FEM and the calculation has coincidence with the result of laser welding experiment. The model is reasonable and welding seams can be predicted, by this model thus it helps to choose appropriate parameters for laser welding of aluminum alloy. It makes the laser welding of aluminum alloy more conveniently used in the industry.

Key words: laser welding; aluminum alloy; finite element

Ultrasonic low-frequency resonant test of spot welding of zinc-coated steel sheet
CHEN Zhenhua[1], SHI Yaowu[1], JIAO Biaoqiang[2], ZHAO Haiyan[3] (1. School of Materials Science and Engineering, Beijing University of Technology, Beijing 100022, China; 2. China Academy of Railway Sciences, Beijing 100081, China; 3. Department of Mechanical Engineering, Tsinghua University, Beijing 100084, China). p101—104

Abstract: High order resonance of the ultrasonic transducer was investigated and adopted to inspect spot weld. The transducer can receive the half-wavelength resonance frequency signals from non-welded thin steel sheet because of the ultrasonic multiple reflect in steel sheet, and the frequency of signals is near the high order resonance domain which is out of the bandwidth of the transducer. These signals can be picked up through wavelet packet transform (WPT) because of their special spectrum localization. Thus, the WPT can be adopted to evaluate the joining quality of resistance spot welding of zinc-coated steel sheet. Through analyzing the signals in different scale, the characteristic number which can determine the quality of the spot weld was obtained. This non-destructive evaluation may be used to quantitatively estimate the quality of spot welds. As the low frequency transducer is used, the testing cost is obviously decreased in comparison to the normal testing.

Key words: high order resonance; non-destructive evaluation; wavelet packet transform; spot welding

Microstructure and mechanical properties of TIG brazing of stainless steel
SONG Jianling, LIN Sanbao, YANG Chunli, FAN Chenglei (State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China). p105—108

Abstract: TIG brazing of stainless steel was carried out with S211 and S201 copper matrix filler metal. The microstructure and mechanical properties of the joint were studied by OM, SEM, EDS, Instron-testing machine, etc. The results show that the joint has a dual characteristic: the up side of the joint and a brazing part in the bottom part. A fusion zone consisting of α and ε phases appears in the upper part and a brazing layer appears in the bottom part, which are joint to the stainless steel soundly. The microstructures of brazed seam are macro-homogeneous supersaturated solid solution of iron in copper matrix and high temperature granules consisting of α and ε distributed unevenly in the brazed seam, which consolidate the tensile strength of the brazed seam. The high temperature granules are distributed more unevenly in upper part than that of in the bottom and the sizes of them are different. Fracture occurs in the brazed seam of the two kinds of joints, S211 joint and S201 joint, in the tensile test. The S211 joint has higher tensile strength than S201 joint, compared 498.33 MPa to 476.67 MPa, whereas the S201 joint has higher extensibility, compared 19.6% to 13.8%.

Key words: TIG brazing; high temperature copper matrix filler metal; microstructure; mechanical properties

Voltage compensation control system in resistance butt welding of copper pipe and aluminum pipe
ZHANG Xichuan[1], ZUO Lina[2], LIU Zhongren[1], AN Zhenzhi[1] (1. College of Materials Science and Engineering, Shenyang University of Technology, Shenyang 110023, China; 2. Northeast General Pharmaceutical Factory, Company of Building and Installation, Shenyang 110026, China). p109—112

Abstract: According to the welding process of copper pipe and aluminum pipe, a PLC control system with the function of voltage compensation was developed to stabilizing the welding electric current and welding quality. Before welding, power voltage was measured, and the angle of flow for silicon control can be calculated by control system, and then transmitted to the trigger circuit board. And the cubic spline was used to fit the relationship of the angle of flow and power voltage. When the voltage waved in the rang of 380 V±15%, $\phi 8\times 1$ copper pipe and aluminum pipe were jointed and the experimental datum of welding electric current was obtained. The result of the T-test to electric current datum shows that the welding current is stable. The welding quality is reliable.

Key words: copper pipe; aluminum pipe; resistance butt welding; voltage compensation