焊接凝固裂纹数值模拟与预测系统后处理设计

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摘 要：设计了三维焊接凝固裂纹的数值模拟与预测软件系统，使普通的焊接技术人员可以简便地实现焊接凝固裂纹的数值模拟与预测. 系统由三部分组成：前处理、后处理和凝固裂纹预测部分. 文中利用工程应用软件的图形函数和矩阵运算函数库对系统后处理进行了设计，实现了对前处理模拟结果的数据处理，处理后的结果以平面曲线、云纹图和三维立体图的形式提供给用户；凝固裂纹预测部分将横向可调拘束试验得到的材料凝固塑性曲线处理，回归成材料的凝固裂纹阻力曲线，并与系统计算得到的凝固裂纹驱动力曲线进行对比，从而实现对焊接过程中凝固裂纹问题的预测.

关键词：凝固裂纹预测；后处理；阻力曲线；驱动力曲线
中图分类号：TG44 **文献标识码**：A **文章编号**：0253－360X(2011)03－0017－04


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0 序 言

以MSC. Marc为基础，在以往凝固裂纹数值模拟研究工作的基础上[1-6]，建立了一个计算机辅助三维焊接凝固裂纹模拟与预测系统，由前处理、后处理及凝固裂纹预测模块组成. 设计了三维焊接凝固裂纹的数值模拟与预测软件系统，使普通的焊接技术人员可以简便地实现焊接凝固裂纹的数值模拟与预测. 系统由三部分组成：前处理、后处理和凝固裂纹预测部分. 其中系统的前处理可以帮助用户选择工件类型，对工件进行网格剖分，输入材料性能参数、焊接条件以及力学边界条件等，并自动以MSC. Marc命令流的形式存储成MSC. Marc的过程文件. 依据生成的过程文件，自行连接MSC. Marc有限元软件，对焊接凝固裂纹的温度场和应力、应变场进行数值模拟计算，并存储模拟结果，为后处理做准备.

文中对三维焊接凝固裂纹模拟与预测系统的后处理进行设计，主要实现二维曲线图、三维焊接温度场、应变场图以及等高云图的显示，最终实现焊接凝固裂纹的预测功能.

1 系统的后处理接口设计

后处理的接口涉及到工程应用软件的图形函数和矩阵运算函数库的调用，主要实现二维曲线图(包括温度和应变循环曲线、温度和应变横纵截面曲线)、三维焊接温度场、应变场图和温度、应变等高云图的显示. 后处理的接口如图1所示.

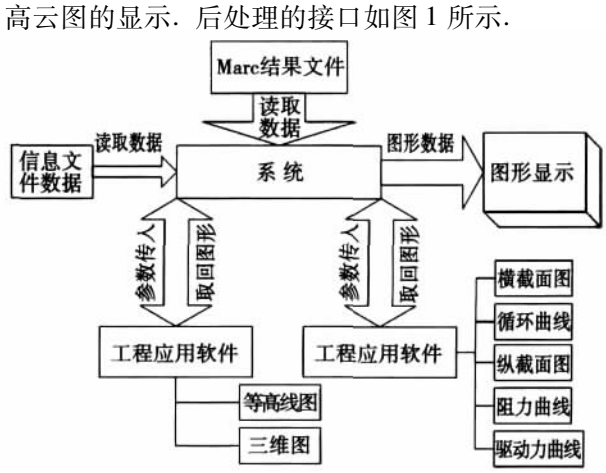

图1 后处理接口
Fig. 1 Interface of post-data treatment

系统读入MSC. Marc模拟运算结果后，将数据整理成系统需要的格式，然后通过信息文件的读入实现接头信息的录入，最终实现接头模型的还原，提交给工程应用软件进行画图，然后取回图形实现结果显示.

2 后处理结果显示

MSC. Marc模拟过程是通过单元的积分点进行

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计算的,数据也是按积分点存储,文中选择八积分点的六面体单元类型进行计算. 在每个增量步内,每个单元输出八个数据值,这样后处理的结果文件很大,系统读取数据速度和数据的处理速度有较大的影响,同时也输出了较多的与需求无关的结果. 因此,系统实现对后处理结果文件有选择性地输出.

用户只需设置时间步、选择坐标点的位置,系统将结果数据处理成各种后处理图形所需的数据形式,用户只需简单地点击按钮,系统就会将五种图形或曲线显示给用户,分别为三维立体图形、等高云图、横向截面曲线、纵向截面曲线和循环曲线.

选择和填写了所有的参数后,系统会自动读入数据并处理成* . MAT 文件,提交到画图功能模块中,用来显示图形.

2.1 绘制三维图形

绘制三维结果图形需要准备的数据,除了模拟结果矩阵、x 轴坐标向量和 y 轴坐标向量以外,还需要提供 x,y 和 z 轴坐标的标度值,其用来控制每个坐标轴的最大坐标和最小坐标值的量.

绘制三维结果图形和等高线图形时的工作模式: 系统准备好矩阵数据后,向绘图软件发出运行绘图命令的请求,绘图软件根据矩阵数据绘制出图形,放在操作系统的缓存中,系统从缓存中获取图形结果,返回到项目界面中显示.

通过对绘图软件功能的调用,可以实现温度场和应变场的三维图和等高云图的显示,图 2 为温度场和应变场的三维图分布状态,给用户以直观的感觉. 用户可通过参数设置界面来设置查看焊接过程中任意时刻整个试件上温度或应变的分布情况及其变化趋势.

2.2 绘制等高云图

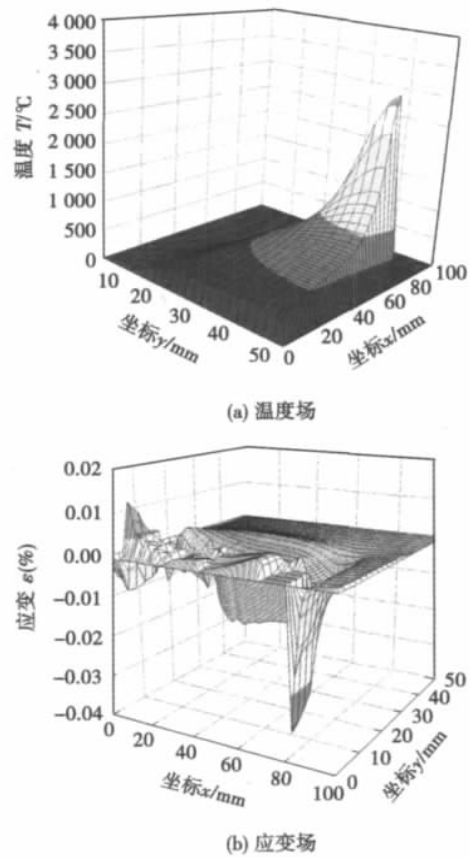
图 3 为某时刻的温度场和应变场的等高云图. 等高云图是利用颜色的变化来表示相应点的值,可以让用户很清晰地看出相应位置的温度或者应变的范围,并可以根据等高云图来确定下一步进行操作.

2.3 绘制曲线

文中将平面曲线绘制及转换工作移交给绘图软件的函数库来完成. 此函数库作为一个动态链接库(DLL) 的形式存在,程序运行时从链接库中寻找相关的数据和功能函数调用支持,在混合编程和系统集成方面有很大的优越性.

经过系统处理,在系统的图片框上显示出温度场和应变场的循环曲线,图 4 是热循环曲线和应变循环曲线.

图 4a 是焊缝中某点经历了加热和冷却的热循环过程,而从图4b中能够看出,在热源到达该点之

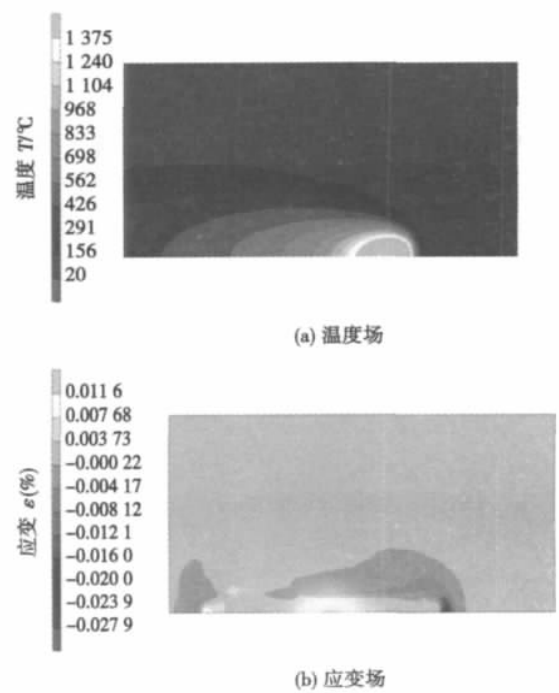


(a) 温度场

(b) 应变场

图 2 三维焊接温度场及应变场分布

Fig. 2 3D thermal and transverse strain distributions



(a) 温度场

(b) 应变场

图 3 二维的焊接温度场及应变场云纹图

Fig. 3 2D contour of thermal and transverse strain distributions

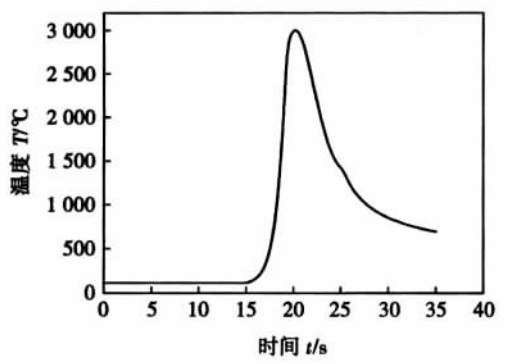


图 4　循环曲线分布

Fig. 4　Distributions of cycle curve

前压应变会急剧增加,然后,由于单元死活技术的处理作用使得处于熔池部分的单元处于自由状态,此时单元的应变值为零,当熔池金属开始凝固,单元开始激活,拉伸应变逐渐增加,这个阶段正处于脆性温度区间内,凝固裂纹在此时最容易产生. 同时系统也提供了模拟结果的截面曲线图显示功能,包括温度场和应变场的横截面曲线及纵截面曲线图.

3　凝固裂纹预测模块

为了预测焊接过程中工件是否产生凝固裂纹,必须把凝固裂纹驱动力曲线和阻力曲线放在一起进行比较.

凝固裂纹驱动力曲线可以通过数值模拟计算获取、凝固裂纹阻力曲线通过横向可调拘束试验方法得到. 文中裂纹预测部分包括数据的读入(阻力曲线数据、温度场数据和应变场数据) 、数据的处理以及阻力曲线和驱动力曲线的画图及显示.

驱动力曲线是焊接接头的某一点上的机械应变随温度的变化,所以,在进行处理之前首先要选择预测点. 预测点的选择可通过参数选择窗体,如图 5 所示,根据网格上的节点,用户可任意选取预测点进行预测.

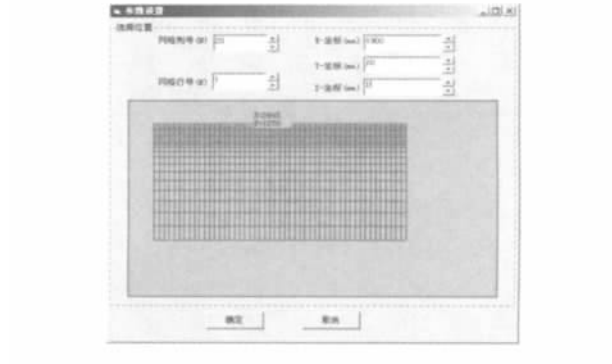


图 5　预测点选择窗体

Fig. 5　Interface of selecting predicted dot

当预测点选择之后,系统将选择点的横纵坐标或单元的行列数提交给下一个功能块,温度场的数据按时间步排列顺序存入行向量. 通过处理得到焊接热循环曲线和应变循环曲线,从而能够获得凝固裂纹驱动力曲线. 凝固裂纹阻力曲线利用横向可调拘束试验方法测量获得,并存储在数据库中. 在进行凝固裂纹预测时,由系统自动读入并拟合,然后与驱动力曲线进行比较,从而对凝固裂纹进行预测.

图 6 为模型中焊缝的起弧点和收弧点的驱动力曲线与测量得到的阻力曲线,根据阻力曲线和驱动力曲线相对位置可以判断是否产生凝固裂纹.

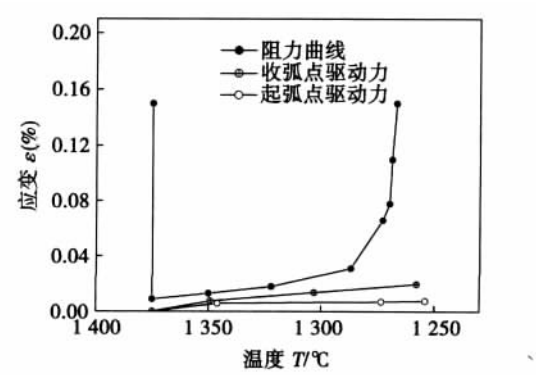


图 6 凝固裂纹的预测图

Fig. 6　Predicating weld metal solidification crack

从图 6 中可以看出,阻力曲线在驱动力曲线上方,并且阻力曲线与驱动力曲线彼此分开,没有相交点,因此,可以预测模型在焊接过程中不会产生凝固裂纹.

4　结　　论

(1) 设计了系统的后处理接口,利用绘图软件,实现了二维曲线图、三维焊接温度场、应变场图和温

度、应变等高云图的显示.

(2) 设计了凝固裂纹预测模块,通过回归阻力曲线与驱动力曲线比较,从而实现凝固裂纹预测.

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MAIN TOPICS, ABSTRACTS & KEY WORDS

Simulation of equiaxed dendritic growth in molten pool of pure metal with phase-field method WEI Yanhong[1,2], WANG Yong[1], DONG Zhibo[1], MA Rui[1], ZHAN Xiaohong[2] (1. State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China; 2. School of Material Science and Technology, Nanjing University of Aeronautics & Astronautics, Nanjing 210016, China). p 1 - 4, 8

Abstract: A coupled model of phase field method and finite difference method was established to study equiaxed dendritic growth in the central area of TIG welded molten pool. In this model, some characteristics of welding pool, such as high cooling rate, short solidification time, and large undercooling degree were taken into consideration. Based on the model, simulation of single equiaxed grain growth in the molten pool of pure nickel was performed successfully. Moreover, the change of dendrite morphology and growth behavior with undercooling in welding pool was studied. The simulation results were in good accordance with the stability theory of interface. Meanwhile, the simulation of multiple grain growth was also presented, which reproduced the competitive growing behavior among side-branches. This study lays a good foundation for further research.

Key words: solidification of weld molten pool; phase-field method; microstructure; numerical simulation

Effect of pin shapes on material deformation and temperature field in friction stir welding ZHANG Zhao[1], LIU Huijie[2,1] (1. State Key Laboratory of Structural Analysis for Industrial Equipment, Department of Engineering Mechanics, Dalian University of Technology, Dalian, Liaoning 116024, China; 2. State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China). p 5 - 8

Abstract: Fully coupled thermo-mechanical model was adopted to study the effect of pin shapes on deformations and temperature fields in friction stir welding. Results indicated that a flatter shoulder could lead to the decrease of temperature and plastic deformation. The efficient power decreased simultaneously. With comparison to the case of cylindrical pin, the temperature decreased in the case of conical pin. The decrease of the frictional heat induced by the decrease of the slipping rate was the reason for such a decrease of temperature. The plastic deformation increased when the conical pin was adopted. When the smaller shoulder was used, the temperature decreased obviously, which was caused by the decrease of the frictional area. So, higher angular velocity should be used when the smaller shoulder was used to improve the welding temperature and the weld quality.

Key words: friction stir welding; fully coupled thermo-mechanical model; finite element method; tool shape

Embedding fiber sensor in 1100 aluminium foil using ultrasonic welding method LI Yulong[1], LI Wei[2], WANG Feifan[1], LIU Fuping[1] (1. Key Lab of Robot & Welding Automation, School of Mechanical & Electrical Engineering, Nachang University, Nanchang 330031, China; 2. China Special Equipment Inspection and Research Institute, Beijing 100013, China). p 9 - 12

Abstract: For embedding fiber sensor in metal, ultrasonic welding of T2 copper and 1100(L4) aluminium were carried out, and the fiber sensor was embedded in copper and aluminium foil. For selecting the protection method for the fiber sensor, the embedded fiber sensors with bare fiber, fiber with chemical plating coat and fiber with chemical-electro plating coat were tested respectively. The embedding strength of the fiber was evaluated by the tensile test and the light intensity loss of the embedded fiber was evaluated by the light detector. The results show that aluminium foil could be used for embedding the fiber sensor. Chemical-electro plating method could be used as the protection method for the fiber sensor. The average embedding strength was 45 N and the light intensity loss was 0.22 dB.

Key words: ultrasonic welding of metal; fiber Bragg grating; electro plating; chemical plating; fiber-smart metal structure

A heat source model for laser heat-conduction brazing ZHAO Pengcheng[1], WANG Lulu[1], LI Shujiang[1], WU Chuansong[2], SHI Ping'an[3] (1. College of Electromechanical Engineering, Qingdao University of Science and Technology, Qingdao, Shandong, 266061, China; 2. Institute of Materials Joining, Shandong University, Jinan 250061, China; 3. Institute of Structural Mechanics, China Academy of Engineering Physics, Mianyang, Sichuan 621900, China). p 13 - 16

Abstract: A heat source model suitable for laser heat-conduction brazing of Beryllium plates was developed according to the weld pool with a characteristic of small depth-width ratio. Three models were established respectively such as the compound heat source model that combined Gauss model with rotary body model in different proportions, the exponential-rotary parabolic body heat source model and the linear-rotary parabolic body heat source model. The thermal cycle curves of a point 2 mm ahead the start point and weld pool contours on cross section were predicted under same welding conditions by the three models, and welding experiments were performed to verify the models. The weld pool contours predicted by the two former models were compared in one experiment and the result showed they were. Meanwhile, it could not obtain a weld pool by using the linear-rotary parabolic body heat source model in current study. Results showed that the exponential-rotary parabolic body heat source model was the best one for its less parameter and good agreement with the experimental results.

Key words: laser heat-conduction brazing; heat source model; exponential-rotary parabolic body heat source

Post-data treatment design of software package for three dimensional simulation and prediction of weld solidification cracks DONG Zhibo[1], MA Rui[1], WANG Yong[2], ZHAN Xi-

aohong[3], WEI Yanhong[1,3] (1. State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China; 2. Shanghai Xin Li Institute of Power Equipment, Shanghai 200125, China; 3. School of Material Science and Technology, Nanjing University of Aeronautics & Astronautics, Nanjing 210016, China). p 17 - 20

Abstract: A software package has been developed which can simulate and predict the weld solidification cracks with three dimensional FEM. It consists of pre-processing, post-processing and solidification cracks predicting subsystem. The post-data treatment of software package for three-dimensional simulation and prediction of the weld solidification cracks can deal with the calculated results and display the results in featured curves, contours and 3D figures by combining graphic functions of softwares. The solidification cracks predicting subsystem regresses to the experimental data of trans-varestraint test (TVT) to obtain the material resistance curve of weld solidification cracks or reads the modified material resistance of simulating TVT from the database and has it compared with the one and thus predict the weld metal solidification cracks.

Key words: solidification cracking; post-data treatment; material resistance curve; driving force

Seam offset identification of underwater arc welding using PCA_Nu-SVR DU Jianhui, SHI Yonghua, WANG Guorong, HUANG Guoxing (South China University of Technology, School of Mechanical & Automotive Engineering, Guangzhou 510640, China). p 21 - 24

Abstract: In order to realize the underwater auto-welding based on rotating arc sensor and get high accuracy tracking, it is necessary to study the seam offset identification algorithm. First, the wavelet and median filter methods were used to process welding current signals, and then the signal was divided into cycle and normalized. PCA was used to remove the self-correlation of data set and reduce the number of inputs of Nu-SVR. The result showed that the maximum error and mean error of PCA_Nu-SVR was 0.95 mm and 0.65 mm. The precision of PCA_Nu-SVR was as good as Nu-SVR, and better than interval integral method and neural network. The runtime of PCA_Nu-SVR was more than interval integral method, and less than neural network and Nu-SVR.

Key words: rotating arc sensor; underwater welding; principal component analysis; support vector regression; seam offset identification

Parameters control for interfacial fracture mode of resistance spot weld dual-phase steels YANG Haijun[1], ZHANG Yansong[1], LAI Xinmin[1], ZHANG Xiaoyun[2] (1. School of Mechanical Engineering, Shanghai Jiaotong University, Shanghai 200240, China; 2. Vehicle Manufacturing Engineering, Shanghai General Motors, Shanghai 201201, China). p 25 - 28

Abstract: In this paper, the response surface method is used to analyze the influence of welding parameters on the interfacial fracture mode of resistance spot welded (RSW) joint made of dual phase steel DP600 with 1.4 mm thickness. The results showed that welding current, welding time and holding pressure were the key parameters to the interfacial fracture mode of the RSW joints. The proper welding parameters can enlarge the weld nugget diameter ratio and reduce its sensitivity to welding parameters. The optimized welding parameters were obtained to control the interfacial fracture mode with the consideration of the robustness of welding process which was validated by experiments.

Key words: dual phase steel; interfacial fracture; improved response surface method; process optimization

Synthetic analysis about effect of GMAW arc to Nd: YAG laser transmitting WANG Wei, LIN Shangyang, WANG Xuyou, LEI Zhen (Harbin Welding Institute, Harbin 150080, China). p 29 - 32

Abstract: From the view of GMAW arc's absorption and refraction to Nd: YAG laser, the phenomena, which when Nd: YAG laser crosses GMAW arc, it's radius will decreases, was analyzed in this paper. The results show that if decreasing of Nd: YAG laser radius is due to absorption of GMAW arc totally, the absorptivity of pulse GMAW arc to Nd: YAG laser is 0.7%, and the absorptivity of short-circuiting GMAW arc is 2.0%. If this phenomena is attributed to refraction of GMAW arc overall, Nd: YAG laser beam is deflected 0.34% by pulse GMAW arc, and 1.02% by short-circuiting GMAW arc. But considering this phenomena form the view of welding, it can regard approximatively GMAW arc as no effect on Nd: YAG laser beam transmitting.

Key words: hybrid welding; laser welding; GMAW; laser absorption; laser refraction

Digital welder parameters self-regulating algorithm based on partial Newton interpolation LIN Fang[1,2], HUANG Wenchao[1], CHEN Xiaofeng[1], WEI Zhonghua[1], XUE Jiaxiang[1] (1. School of Mechanical & Automotive Engineering, South China University of Technology, Guangzhou 510640, China; 2. Department of Electromechanical Technology, Jiangmen Polytechnic, Jiangmen, Guangdong 529000, China). p 33 - 36

Abstract: A welding parameter self-regulating algorithm based on long-step calibration and partial Newton interpolation were put forward. By this algorithm, not only the unified parameters regulation could be realized, but also the database of the digital welder could be transformed from static mode into dynamic mode, in which the self-learning and self-regulating function were adopted. It might provide an effective strategy for the intelligent evolution of the digital welder. The results of the tests indicated that the welding parameters could be continuously self-regulated in a wide range. By the P-GMAW parameters generated by this algorithm, a stable welding process and well-formed seams could be acquired. By employing the parameter storing method with various priorities, the optimization of the parameters could be achieved.

Key words: digital welder; long-step calibration; partial Newton interpolation; self-regulating algorithm

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