双面 T形焊件中批量缺陷空间定位数据的自动提取

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摘　要：提出了双面 T形焊件中小缺陷的空间位置数据自动提取算法．该算法主要由两部分组成：一是自动提取投影距离和缺陷距焊缝上端的距离，二是自动提取缺陷尺寸和缺陷距焊缝上端的距离．设计了双面 T形焊件左右旋转图像中缺陷的自动对应准则，实现了其内部小缺陷空间位置数据的快速提取．采用实际焊件破坏性试验的方法对上述算法进行了验证．结果表明，文中提出的算法是可行的．

关键词：双面 T形；激光焊件；X射线图像；空间定位数据；自动提取
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0　序　　言

缺陷定位方面的研究一直是无损检测中的热点和重点．近年来无损检测专家在普通结构焊缝中大缺陷的超声、射线深度定位方面开展了一定的研究，取得了一定的可喜的成果[1－3]，而对于精密焊缝中小缺陷的空间定位方面的研究较少．文中的研究对象为双面 T形焊件，是采用激光焊把筋板和蒙皮连接到一起，焊件正反面均有激光焊缝，且焊缝尺寸和缺陷均较小，缺陷距焊缝表面较近，超声检测时由于盲区的存在不适于该焊件的检测．射线检测时把焊件的三维信息压缩到二维平面上，一般不利于焊缝中缺陷深度的测定，但采用旋转焊件的方法可实现焊件中小缺陷的检测，结合建立的深度、偏移量数学模型可实现缺陷的空间定位[4,5]．由于该焊件中包含的小缺陷如气孔等较多，采用手动方法确定缺陷的空间位置成本高、效率低、准确性不高，因此需开发自动提取算法来实现焊缝中批量缺陷的空间定位．

文中提出了双面 T形激光焊件内部批量缺陷空间位置数据自动提取的算法，并对实际焊件中的缺陷进行了自动提取和验证，验证结果表明提出的算法是可行的，这为后续的批量缺陷空间位置数据可视化和精密焊件接头的结构完整性评价奠定了良好的基础．

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1　缺陷空间定位模型的建立

双面 T形焊件的局部结构为工字形，图 1为外观图，属蒙皮框架结构，蒙皮与框架间采用激光焊连接到一起．在目前的焊接工艺下其接头处的缺陷全部为气孔，图 2为局部剖面图．

图 1　焊件局部外观图
Fig.1　Outside view of partial weldments

图 2　横断面局部图
Fig.2　Partial drawing of transverse section

该结构的最薄弱环节为焊件结合面位置，因此

气孔缺陷在焊缝中的位置对焊接接头的性能有很大的影响. 该件焊缝尺寸小，缺陷尺寸也较小. 为了确定焊缝中缺陷的空间位置，文中采用左右旋转焊件的成像方法对其进行了检测，并分别获得了该焊件在不同检测位置的射线图像，其检测工艺参数见表 1，检测屏 SCR的直径是 5英寸.

表 1 检测工艺参数

Table 1 Technology parameters of detection

管电压 U/kV	管电流 I/mA	焦点尺寸 D/mm	焦距 F/mm	放大倍数 M
61	7.85	0.4×0.4	428	1.5

为了确定缺陷在焊缝中的空间位置，在分析焊件结构和图像几何关系的基础上建立了缺陷的深度和偏移量数学模型，其沿焊缝纵向的位置可通过图像处理的方法获得；因此其空间位置可确定下来，这对于该结构的无损检测及接头完整性评价可提供有价值的参考信息. 图 3是缺陷深度数学模型建立的示意图，图 4是缺陷偏移量数学模型建立的示意图[6].

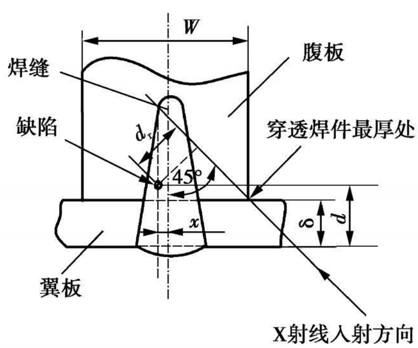

图 3 缺陷深度数学模型建立的示意图

Fig. 3 Schematic of derivation mathematic model for defect depth

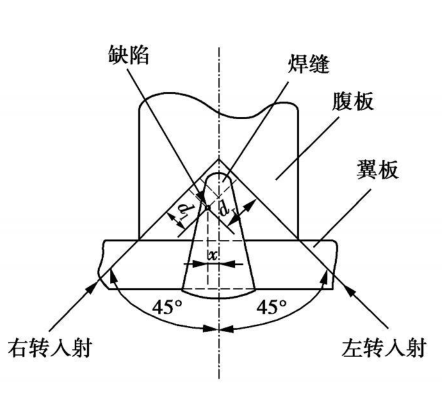

图 4 缺陷偏移量数学模型建立的示意图

Fig. 4 Schematic of derivation mathematic model for defect deviation

根据图 3和图 4中的几何关系，可以得到如下的缺陷深度和偏移量计算的数学模型，即

$$d = \left(\frac{W}{2} + x + \delta\right) - \sqrt{2}\, d_r \tag{1}$$

$$x = \frac{d_r - d_l}{\sqrt{2}} \tag{2}$$

式中：d为缺陷中心到翼板表面的距离（mm）；d_l为焊件右转时缺陷中心到穿透焊件最厚处的投影距离（mm）；d_r为焊件左转时缺陷中心到穿透焊件最厚处的投影距离（mm）；W为腹板宽度（mm）；δ为翼板厚度（mm）；x为缺陷偏离焊缝中心的距离（mm）.

当 $x>0$时缺陷位于焊缝中心的左侧；当 $x=0$时缺陷位于焊缝中心；当 $x<0$时缺陷位于焊缝中心的右侧.

2 缺陷空间定位数据的自动提取

在上面的深度和偏移量数学模型里只要确定了投影距离，就可实现缺陷深度和偏移量的自动提取，同时可以设计算法自动计算缺陷半径的大小和距图像一端的距离. 由于同一位置的检测图象中有许多缺陷，因此可通过对比缺陷距图像一端的距离自动把缺陷的三维位置及其半径对应到一起，也就实现了批量缺陷空间位置数据的自动提取. 该方法减少了人为因素的干扰，大大提高了双面 T形结构焊件的检测效率，对于提高检测的自动化和鲁棒性有着积极的意义. 图 5为批量缺陷空间位置数据自动提取的算法流程图，其中计算气孔半径的方法采用的是扫描标号法[7]，其算法思想如下：（1）首先进行从左到右，从上到下扫描，在同一行中不连通的行

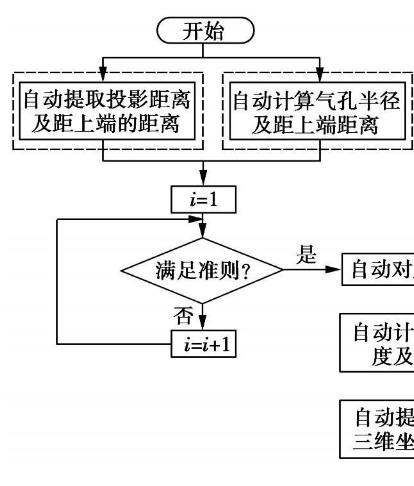

图 5 缺陷空间位置数据自动提取的算法流程图

Fig. 5 Flowchart of automated extraction algorithm for defect spatial location

程 (灰度级相同的点)标不同的号, 不同的列标不同的号; (2) 从左上到右下扫描, 如果两个相邻的行中有相连通的行程则下行的号改为上行的号; (3) 从右下到左上扫描, 如果两个相邻的行中有相连通的行程则上行的号改为下行的号; (4) 再对标过的号进行排列; (5) 通过对图像进行标号后, 可对不同缺陷的面积进行测量. 主要是对相同号的点进行累加, 之后得到缺陷的像素点的总和即为缺陷的面积, 从而缺陷的半径可根据公式得到.

对双面 T形焊件左右旋转图像进行缺陷分割后, 采用上述自动提取算法对检测图像中的缺陷进行提取和对应, 即可计算出缺陷的三维位置信息及缺陷半径. 自动对应的缺陷数据见表 2和表 3.

表 2　正面焊缝气孔 (z49)
Table 2　Porosities in front face weld

序号	缺陷偏移量 x/mm	缺陷距焊缝一端的距离 y/mm	缺陷深度 z/mm	气孔缺陷半径 r/mm
1	0 11	2. 59	0 88	0 26
2	−0 09	12. 58	0 88	0 28
3	−0 02	18. 48	1. 15	0 23
4	0 08	23. 38	0 77	0 23
5	0 55	23. 62	1. 25	0 12
6	1. 03	23. 62	0 77	0 12
7	0 04	28. 22	1. 15	0 29
8	0 08	37. 01	0 84	0 22
9	0 01	39. 94	1. 05	0 16
10	0 15	45. 41	0 98	0 26
11	−0 09	54. 29	1. 42	0 27

表 3　背面焊缝气孔 (z50)
Table 3　Porosities in back face weld

序号	缺陷偏移量 x/mm	缺陷距焊缝一端的距离 y/mm	缺陷深度 z/mm	气孔缺陷半径 r/mm
1	−0 17	5. 18	0 68	0 29
2	−0 24	6. 62	1. 29	0 20
3	−0 11	10. 18	1. 02	0 20
4	−0 38	12. 91	0 82	0 24
5	−0 21	22. 03	1. 60	0 23
6	−0 34	24. 62	1. 46	0 23
7	−0 41	25. 63	1. 32	0 27
8	−0 21	38. 54	0 92	0 27
9	−0 24	41. 57	1. 02	0 28
10	−0 14	43. 30	1. 19	0 26
11	−0 21	49. 34	0 98	0 38

3　试验验证

采用与实际产品相同的焊接工艺参数制备了试件, 文中验证的气孔缺陷总样本数为 115个, 气孔深度计算值和测量值的绝对误差在 0. 12 mm以内, 其平均相对误差为 5. 13%. 图 6为纵断面的金相形貌, 图中标出了验证气孔的位置. 缺陷深度测量值与计算值的线性关系曲线见图 7, 其平均相对误差分布曲线见图 8. 从图中可以看出只是在 0% ~1%之间有一个异状突起, 其误差大致呈以 5%为中心的正态分布.

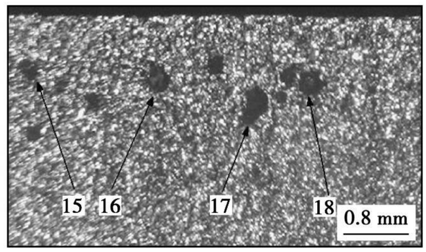

图 6　纵剖面金相形貌
Fig. 6　Metallograph of longitudinal section

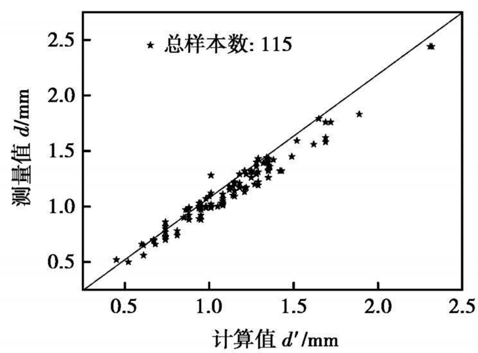

图 7　缺陷深度测量值与计算值的关系
Fig. 7　Relationship of measured values and calculated values for defects depth

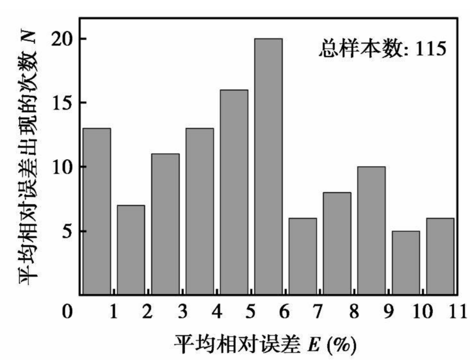

图 8　误差分布
Fig. 8　Error distribution

在下一步工作中将开展双面 T形焊件三维建模和缺陷空间位置可视化等方面的研究, 进一步为

其快速无损检测和结构完整性评价提供有价值的参考信息.

4 结　论

(1) 提出了双面 T形焊件中气孔缺陷的深度及偏移量的数学模型,对其内部缺陷进行了有效的空间定位.

(2) 设计了双面 T形焊件中批量气孔缺陷的空间位置数据自动提取算法,实现了其空间位置数据的快速提取,为后续的缺陷可视化奠定了良好的基础.

(3) 采用破坏性试验的方法对上述算法进行了验证,实际焊件中缺陷验证结果表明缺陷深度计算值和测量值的绝对误差在 0.12 mm以内,其平均相对误差为 5.13%.

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[上接第 68页]

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rate environmental noise from arc sound signal. The ICA separating technology provides technical basis for extracting characteristics of arc sound signal and monitoring welding quality via arc sound signal.

Key words: arc sound; independent component analysis; fast fixed-point algorithm; signal and noise separation

Simulation of microstructure formation during solidification in weld pool LI Yubin, MENG Daqiao, LIU Kezhao, XIE Zhiqiang (P. O. Box919, China Academy of Engineering Physics, Mianyang 621900, China). p 57—60, 64

Abstract: Base on the kinetics of the dendritic tip growth and least energy of grain growth theory, a two-dimension CAMC (Cellular automata-Monte Carlo) grain growth mathematical model for weld pool which couples macroscopic heat transfer with microscopic solute transfer, nucleation and growth is developed. The skeleton of grain is formed by using CA model, and then the growth of grain is corrected by MC model. In the model, the mechanism and influencing factors of heterogeneous nucleation, which occurs at the boundary of welding zone, are taken into account. The dynamic process of microstructure formation in welding zone is presented. The evolution of amount, dimension and appearance of grains can be described quantitatively by using CAMC model, and the choosing growth of grain and the transition from columnar to equiaxed crystal can be exhibited by model. It is successful to simulate the microstructure evolvement during metal solidification of welding zone by CAMC model.

Key words: weld pool; grain growth; numerical simulation; cellular automata; Cellular automata-Monte Carlo model

Microstructures and bulging formability of laser welded tailored blanks for high strength steel with unequal thickness LU Guangda[1,2], LI Yuntao[1,2], ZHANG Jian[1,3], BI Dasen[1,3] (1. School of Materials Science Engineering, Tianjin University of Technology, Tianjin 300384, China; 2. Tianjin Key Laboratory for Photoelectric Materials Devices, Tianjin University of Technology, Tianjin 300384, China; 3. Key Laboratory of Display Materials Photoelectric Devices Ministry of Education, Tianjin University of Technology, Tianjin 300384, China). p 61—64

Abstract: Tailor welded blanks (TWB) of laser weld is adopted to weld high strength steel sheets SAPH440 with 1.8 mm thickness and DP600 with 2.2 mm thickness. The microstructures and microhardness of the welded joint for TWB are studied, and the cupping tests are carried out to study the bulging formability of TWB, which is compared with that of the original sheet blanks. The results show that the microstructures of the joint are acicular ferrite and lath martensite, the microhardness of the joint is higher than that of the base metal. And the cupping experimental values of TWB are lower than that of the original sheet blanks. Eventually, the weld location has some influence on the bulging formability of TWB, the bigger the proportion of the thin blank is, the better the bulging formability of TWB is, and the weld will move to the side of the thick blank during bulging formation.

Key words: unequal thickness; high strength steel; tailor weld blanks; bulging formability

Interface deformation and its role of steel 45 in vacuum diffusion welding PAN Jinzhi, REN Ruiming, QI Zhengfeng (School of Materials Science and Engineering, Dalian Jiaotong University, Dalian 116028, China). p 65—68, 72

Abstract: The plastic deformation of weld interface under the welding pressure was investigated during the vacuum diffusion welding process of steel 45, and the effects of deformation rate on the welding quality and the process planning was discussed. The results show that the important factor affected on the quality of the vacuum diffusion welding process of steel 45 is the deformation rate under the fixed pressure. The temperature, pressure and holding time have relatively small influence on the welding quality when the deformation rate is beyond a critical value, which the whole welding interface achieves superposition completely by means of plastic deformation. The annealing treatment of post weld can improve the welding strength by changing the microstructures of the interface zone, and the holding time shortens.

Key words: steel 45; diffusion welding; process planning

Automated extraction of spatial locating data for bulk defects in double T joints SHI Duanhu[1], GANG Tie[2], HUANG Chuanhui[1], YANG Genxi[1] (1. School of Electromechanical Engineering, Xuzhou Institute of Technology, Xuzhou 221008, China; 2. State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China). p 69—72

Abstract: The automated extraction algorithm of spatial position data was provided for small defects in double T style weldments. It consists of two parts, one is that automatically extracts projection distance and the distribution of defects along the weld longitudinal direction, and the other is that automatically extracts defect dimension and the distribution of defects along the weld longitudinal direction. Automated corresponding criterion is designed for the defects of left and right turning images in double T joints, and quick extraction of spatial position data for small defects is achieved. Then algorithm verification is carried out by using destructive test of real weldments. The results show that the provided algorithm is feasible in this paper.

Key words: double T style; laser weldments; X-ray image; spatial position data; automated extraction

Friction stir welding of thick copper plate HE Diqiu, YI Xin, LI Zaihua (Key Laboratory of Design for Modern Complex Equipment and Extreme Manufacturing Ministry of Education, P. R. China, Central South University, Changsha 410083, China). p 73—76

Abstract: Friction stir welding is a solid-state welding technique, which may offer a new solution for thick copper plate joining. Friction stir welding of T2 copper plate, 25 mm in thickness, was completed successfully by single pass welding, and the microstructure, physical property, electrical property and energy spectrum of the T2 copper joint were analyzed. The ex-