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动力机车转向架侧梁焊接变形预测

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摘 要：转向架是动力机车的最重要的承载结构，其焊接变形预测对于保证加工精度和质量具有重要意义．首先通过大量的计算和实测建立了转向架结构的固有应变数据库，然后运用基于固有应变的弹性有限元分析的焊接变形预测专用软件 WSDP对六轴式转向架侧梁焊接变形进行预测，预测结果与试验数据具有很好的一致性，所建立的固有变形数据库的可靠性得到验证，研究表明 WSDP软件是大型复杂结构的焊接变形预测的有力工具．

关键词：焊接变形；固有应变；WSDP软件；转向架侧梁
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0 序 言

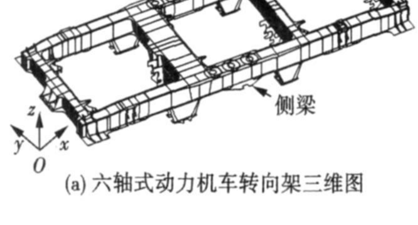
转向架是动力机车的基础结构，也是最重要的承载结构，一般由前端梁、后端梁和侧梁等组成梁焊接而成．转向架各梁的焊接变形决定了加工面的位置精度，直接影响转向架的产品质量．在生产过程中，必须控制组成梁的焊接残余变形，以保证转向架的加工面符合设计要求．组成梁焊接残余变形超出设计尺寸要求时，必须采取火焰或者机械的方法矫正，不但增加加工成本，延长生产周期，而且还使得残余应力的分布状态恶化[1,2]．

通过优化焊接工艺，例如确定合理的焊接变形补偿余量、焊接温度场和工装夹具，是控制焊接变形的最有效的方法[3]．而焊接变形预测是优化焊接工艺方案的前提．预测所得数据可为焊接工艺设计提供理论依据，以保证转向架的焊接质量[4]．

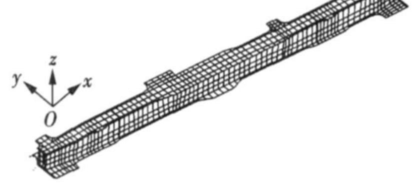
焊接结构尤其是大型复杂焊接结构的焊接变形预测是非常复杂的问题．基于固有应变理论，采用弹性板单元有限元法预测焊接变形是目前采用较多的近似计算方法[5,6]．焊接变形专用预测软件 WSDP(welding structure deformation prediction)是由上海交通大学和日本大阪大学共同开发的固有应变法焊接变形预测软件．文中将应用 WSDP软件，通过大量的计算和实测，建立转向架结构的固有应变数据库，然后对新设计动力机车车型的转向架侧梁焊接变形进行预测，所获得的焊接变形预测数据，为确定预留焊接变形余量的下料尺寸及焊接工艺设计提供理论依据．

1 研究模型

六轴式动力机车是一种新型动力机车．其转向架结构如图 1所示．该结构由前端梁、后端梁、侧梁和牵引梁组成，材料为 Q345DR．在生产过程中，先分别焊接单根梁，然后再把单根梁组焊成转向架构



(a) 六轴式动力机车转向架三维图



(b) 侧梁有限元模型

图 1 六轴式动力机车转向架三维图和侧梁有限元模型
Fig. 1 3D construction and FEM model of hexad-axled locomotive bogie

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架结构. 由于单根梁各构件板尺寸大, 形状复杂, 焊缝分布密集, 施焊位置特殊, 所以, 在生产单根梁过程中, 将产生较大的焊接残余变形. 文中主要以转向架侧梁为研究对象.

侧梁是由上盖板 (左盖板、中盖板、右盖板共 3块盖板), 立板 (前立板、后立板共 2块立板), 底板 (左底板、中底板、右底板共 3块底板)以及 29块隔板及加强筋焊接而成的箱形梁. 侧梁整体长 6 750 mm, 高 394 mm.

应用 HyperMesh软件建立侧梁有限元模型, 采用四边形弹性板单元, 共有节点 2 075, 单元 2 100.

2　焊接变形预测

2.1　专用固有应变数据库的建立

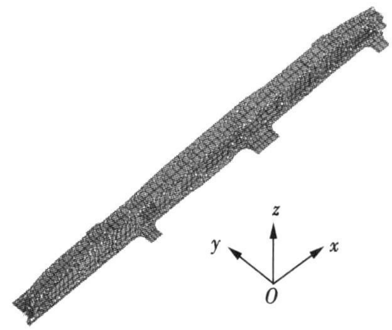
经过一次热循环过程后在结构内部一定存在一个产生残余应力和变形的“源”—固有应变, 如果不追究热循环过程, 在结构中施加与固有应变相等的初始应变, 通过一次弹性板单元分析求解就可以得到整个复杂结构的变形. 所以, 通过固有应变法计算焊接变形的关键是获得固有应变. 然而, 由于焊接过程的复杂性和随机性, 焊缝精确的固有应变值很难获得, 只能通过计算、实测以及现场经验的整理得到符合统计规律的近似值. 对于不同的结构要利用 WSDP软件进行焊接变形预测计算, 必须先要建立固有应变数据库, 这是进行焊接变形预测计算的重要和关键一环.

首先利用热弹塑性有限元法对典型焊缝进行分析, 计算得到不同焊缝的固有应变; 然后根据生产工艺条件和实际生产过程中积累的大量经验数据对固有应变基础数据库进行修正. 具体做法是: 先用 WSDP软件对生产中 JD—4型动力机车转向架构架的焊接变形进行分析, JD—4型动力机车是工艺成熟、在批量生产的一种车型, 焊接变形规律已经比较清楚. 通过计算得到的数据和实际生产中的数据进行对比, 修正固有应变数据库, 建立转向架的专用固有应变数据库. 只有不断修正不同焊接条件下的固有应变数据库, 才能不断地提高预测精度; 因此, 固有应变数据库还需要在实际中长期充实和不断完善.

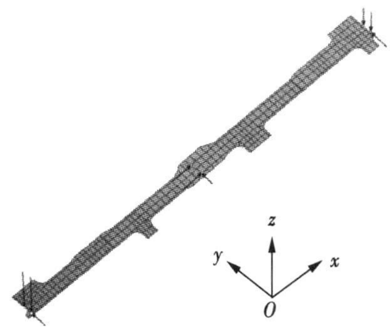
下面采用了修正后的转向架焊接专用的固有应变数据库, 对新型号的六轴式动力机车转向架侧梁进行焊接变形预测.

2.2　六轴式动力机车转向架侧梁焊接变形预测

该结构有 85条焊缝, 参见图 2a点线所示. 施加焊缝固有应变信息时, 首先根据工程图纸在有限元模型上指定焊缝位置, 然后逐个对每条焊缝按照母材、接头类型、焊接方法、板厚和焊缝横截面积等相关条件, 在数据库中查取固有应变, 用纵向力、角变形和横向收缩的方式施加在对应的焊缝中.



(a) 施加焊缝载荷



(b) 施加约束

图 2　侧梁焊缝信息及边界约束条件

Fig. 2　Information and boundary constraints of side beam weld (SBW)

由于工程实践主要关心在长度方向上的收缩变形和高度方向上的挠度, 所以计算中采用了如图 2b所示的边界约束条件. 边界约束条件施加在底板上, 这个边界条件主要防止结构的刚体位移.

2.3　焊接变形预测计算结果

焊接变形预测结果如图 3, 图 4所示. Δ_x和 Δ_z分别表示了 x, z方向的变形量。预测得到的 x方向

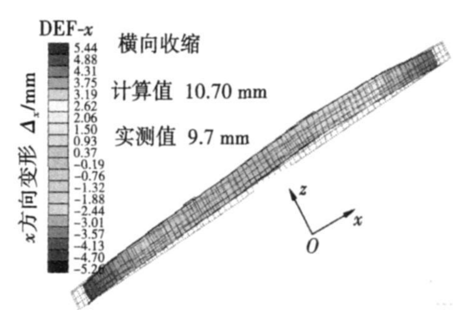


图 3　转向架侧梁焊接 x方向变形分布

Fig. 3　Welding deformation of SBW in x direction

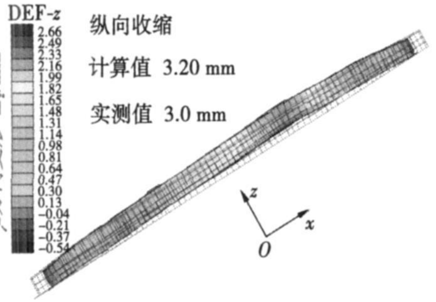


图 4 转向架侧梁 z方向变形分布

Fig. 4 Welding deformation of SBW in z direction

上的总变形量是 10.7 mm, z方向上变形量即挠度为 3.2 mm.

2.4 试验方法和数据及与计算结果对比

同样的条件下,试制转向架侧梁并测量主要板件的焊前焊后尺寸,得到试验数据. 试验的具体方法是:使用 3维画线仪测量并记录上下盖板和立板的长度;按照工艺要求进行焊接;焊后适当冷却,达到室温以后,采用 3维画线仪测量并记录上下盖板和立板的焊后长度. 为了保证试验的可靠性,按照上述方法分别试制了两根侧梁. 两根侧梁的试验数据平均,作为最后的试验结果数据. 具体试验数据与计算数据对比如表 1所示. 试验测得 x方向上平均变形量为 9.7 mm, z方向上挠度平均值为 3.0 mm.

如表 1所示,计算结果和实测结果具有很好的一致性,软件计算精度可以达到 90%左右. 这表明专用数据库的正确性和 WSDP软件焊接变形预测的可靠性. 变形预测的结果经试验证明可以为上下盖板和立板的落料尺寸提供依据.

表 1 转向架侧梁焊接变形计算结果与试验数据对比

Table 1 Comparison between results and experimental data of side-beam of bogie

梁体尺寸	焊接前 L_1/mm	焊接后 L_2/mm	实际变形量 Δ_1/mm	软件计算变形量 Δ_2/mm	软件计算精度(%)
立板(侧梁 1)	6 582	6 572.3	9.7	10.70	90.65
盖板(侧梁 1)	6 575	6 565.3	9.7	10.70	90.65
挠度(侧梁 1)	0	3.0	3.0	3.20	93.75
立板(侧梁 2)	6 582	6 572.5	9.5	10.70	88.79
盖板(侧梁 2)	6 577	6 567.1	9.9	10.70	92.52
挠度(侧梁 2)	0	3.0	3.0	3.20	93.75

3 结 论

(1)通过固有应变法预测,得到六轴式动力机车转向架侧梁的焊接收缩为 11.05 mm,挠度值为 3.06 mm. 与实测值相吻合.

(2)通过热弹塑性计算和生产经验整理而建立的转向架固有应变数据准确.

(3)WSDP软件对于大型复杂结构的焊接变形预测计算简单、实用、准确,是可靠的焊接变形专用预测软件.

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Welding Technology, Jiangsu University of Science and Technology, Zhenjiang 212003, China). p 93—96

Abstract: An aluminum alloy sheet 2A12-T4 two millimeters thick was welded in friction stir spot welding with re-filling probe hole, and the influence of processing parameters on mechanical properties of joint was studied. The results show that the shearing resistance of the joint reaches the maximum value of 4 707 N when rotational speed is 600 r/min and other parameters keep constant. The shearing resistance of joint decreases with the increasing of rotational speed in range from 600 to 1 000 r/min, increases with the increasing of the distance of shoulder plunged, which reaches maximum when the distance of shoulder plunged is 1.2 mm, and increases with the increasing of extension length of pin-tool which reaches the maximum when the extension length is 3.4 mm. The micro-hardness of the joint is between 100 to 150 HV, and that in mixed zone is highest and that in stir zone is lowest.

Key words: friction stir spot welding; probe hole; processing parameter; microstructure

High-frequency induction brazing of YG8 sintered-carbide to mild steel LI Zhuoran, LIU Bing, FAN Jianxin, FENG Jicai (State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China). p 97—100

Abstract: YG8 sintered-carbide and mild steel was joined with BNi2 brazing filler metal and with the high frequency induction brazing. The high-frequency induction brazing equipment was rebuild, which measures the real-time temperature with the thermocouple thermodetector and controls the heating temperature of the equipment with the PID controller. The effect of processing parameters including brazing temperature and holding time on the joint mechanical property was discussed by scanning electron microscopes and energy dispersive X-ray spectroscopy. Results show that the maximum shear strength is 441 MPa when the brazing temperature is 1 030 ℃ and holding time is 5 min. In this case, fracture happens mainly at the YG8 sintered-carbide or the brazing seam.

Key words: sintered-carbide; high frequency induction brazing; shear strength

Analysis of exposed particles and mechanical performance of brazing joints of SiC_p/2024Al composites FENG Tao[1], WANG Yinzhen[1], SUN Yuwei[1], YI Dongxu[1], LOU Songnian[2] (1. College of Mechanical & Electronic Engineering, China University of Petroleum, Dongying 257061, China; 2. School of Material Science and Engineering, Shanghai Jiaotong University, Shanghai 200030, China). p 101—104

Abstract: The effect of brazing parameters on the vacuum-brazing microstructure and mechanical performance of SiC_p/2014Al aluminum matrix composite (MMC) was studied. The SiC reinforcements on the parent composite surface were exposed by the surface reinforcement exposing technique, and then Cu was deposited on the parent matrix composite. By using M6 aluminum alloy as the filler metal, the parent composites were brazed under several different parameters. The test results show that if the brazing temperature is lower or the keeping time is shorter, there is Cu retained on MMC surface. With the increasing of brazing parameters (brazing temperature and keeping time), Cu reacts with Al base metal completely. If the brazing parameters are too high, the porosities by over-burning appear in the base metal. X-ray diffractometry analysis indicates that there is no Al_4C_3 brittle phase formed in the brazing joint. The tensile test indicates that the strength of the joint is 202 MPa at brazing temperature 620 ℃ and keeping time 20 min. The fractography of the brazing joint indicates that the filler metal is un-wetting to the parent composite, the porosities in the parent composite and the aggregated particles in the parent composite are the reasons for the joint cracking.

Key words: aluminum matrix composite; reinforcement exposing; surface alloying; brazing

FEM analysis of distribution of residual thermal stress at Ti-alloy/stainless steel brazed joint WANG Guojian[1], ZHOU Jianyong[1], XU Fang[1], SUN Dong[1], ZHU Ying[2] (1. Key Laboratory of High Power Microwave Sources and Technologies, Institute of Electronics, Chinese Academy of Sciences, Beijing 100190, China; 2. Beihang University, Beijing 100195, China). p 105—109

Abstract: The influence of welding parameters on residual stress distribution and the residual stress field of TC4 and 1Cr18Ni9Ti brazed joint were analyzed with finite element model (FEM) method. The results indicate that the stress concentrates on the both sides of joint, becomes the positive maximum on 0.45 mm beside the Ti-alloy, and is the smallest at the gap length of 50 μm and linear expansion coefficient of 12×10^{-6} ℃$^{-1}$. Bonding temperature influences little on the stress distribution and stress concentration.

Key words: Ti-alloy; residual stress; bonding temperature; expansion coefficient

Welding deformation prediction of side-beam of locomotive bogie frame ZHANG Sanlei[1], LUO Yu[1], CHEN Buyou[2] (1. School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiaotong University, Shanghai 200030, China; 2. Zhuzhou Electrical Locomotive co., LTD, Zhuzhou 412001, China). p 110—112

Abstract: The bogie frame is the most important bearing structure of the locomotive, and its prediction of welding deformation has important significance in ensuring manufacturing accuracy and quality. First, the database of inherent strain for bogie frame structure was established by a lot of computing and practical measure. Then the welding deformation of hexad-axled locomotive bogie frame side-beam was predicted by using software WSDP (welding structure deformation prediction), which is based on the theory of inherent strain and elastic finite element model. The results were totally consistent with experimental data, and the reliability of the database was proved. The study shows WSDP is very useful in welding deformation prediction of large and complex structures.

Key words: welding deformation; inherent strain; software WSDP; bogie side-beam