热点应力法评定焊接接头疲劳强度的影响因素

彭 凡, 姚云建, 顾勇军
(湖南大学 机械与运载工程学院, 长沙 410082)

摘 要: 将三种方法确定的热点应力作为控制应力, 引入焊接接头的疲劳切口系数, 由 Taylor的临界距离理论得到该系数. 通过讨论接头类型、焊缝局部尺寸、板厚以及热点应力的确定方式对疲劳切口系数的影响, 揭示热点应力法进行焊接接头疲劳评定的影响因素. 结果表明, 腹板厚度与焊缝局部几何尺寸对疲劳切口系数的分散性影响较小, 但主板厚度的效应明显, 由疲劳切口系数得到的板厚效应预测与试验结果接近; 以两种外推法为基础构成的热点应力法能明显减少疲劳数据的分散性及其对接头类型与载荷形式的依赖性.

关键词: 焊接接头; 疲劳强度; 热点应力; 临界距离; 疲劳切口系数
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彭 凡

0 序 言

焊接接头疲劳评定方法主要有名义应力法、热点应力法、基于裂纹扩展的断裂力学方法以及局部法等[1-4], 其中, 热点应力法在工程上的应用越来越广泛和深入. 因此, 针对该方法的相关理论与应用途径进行研究就显得十分有意义. 文献[5, 6]讨论了热点应力外推方法、有限元分析模型以及有限元网格密度等因素对计算精度的影响规律. 文中在三种热点应力确定方法的基础上, 由疲劳切口系数分析热点应力的确定方式、接头类型、焊缝局部尺寸以及主板和腹板厚度这些因素对疲劳强度评定的影响.

1 基本理论

热点是疲劳裂纹的起源部位, 具有优良焊接质量的焊接结构之热点一般位于焊趾处. 而热点应力就是热点处的结构应力(几何应力), 与焊接结构的整体几何形状以及受载条件有关, 但不包括焊缝尺寸与焊接缺限等局部因素所引起的应力集中. 热点应力值一般通过有限元计算和试验测试得到, 类似文献[6], 文中采用下述三种方法确定热点应力. t为主板厚度.

(1)以距离热点 0.5t和 1.5t为参考点进行线性外推(包括 DNV在内的多家船级社推荐);

(2)以距离热点 0.4t和 1.0t为参考点进行线性外推(国际焊接学会 IIW推荐);

(3)直接取距离热点 0.5t(t≤10 mm)或 5 mm(t>10 mm)处的应力值的 1.12倍作为热点应力值.

前两种方法为线性外推法, 如图 1所示, 热点应力由参考点 A和 B的应力值线性外推至焊趾处得到.

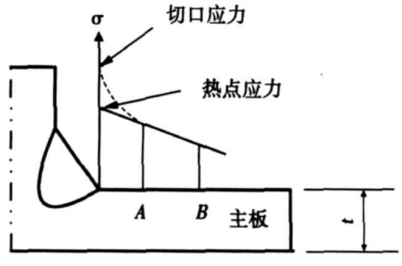

图 1 热点应力的定义

Fig. 1 Definition of hot spot stress

大量的研究表明, 缺口构件的疲劳强度不仅取决于缺口局部最大应力, 面且还与围绕最大应力点某一距离内的整体应力水平有关, 即与局部应力梯度相关. 根据 Taylor的临界距离理论[7,8], 如图 2a所示, 在围绕热点一定临界距离内的平均应力是控制热点疲劳形为的有效局部参量, 当其达到相应的临界值时, 热点发生疲劳开裂. 临界距离理论包括点法、线法、面法与体法. 其中, 线法的主要思想是将自切口根部引出的某一特定线段上的局部应力进

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行平均，该线段长为 $2a$；此处 a为临界距离参数，根据试验数据确定，也可由 EIHaddad的短裂纹理论给出为[9]

$$a=(1/\pi)(\Delta K_{th}/\Delta\sigma_0)^2 \quad (1)$$

式中：$\Delta\sigma_0$与 ΔK_{th}分别是光滑试样的疲劳极限和疲劳裂纹扩展门槛值. 如图 2b所示，将焊趾处的局部形状简化为理想的 V形缺口，文中采用线法计算当量应力，即图 2b中角平分线延长线 x方向上距焊趾 0～2 a范围内应力的平均值.

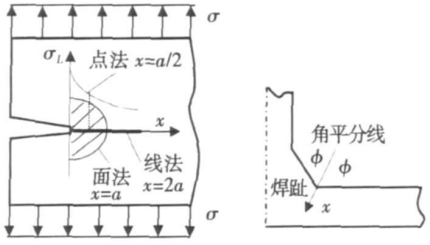

图 2 临界距离法

Fig. 2 Theory of critic distance

$$\sigma_{eq}=\frac{1}{2a}\int_0^{2a}\sigma_L\,dx \quad (2)$$

式中：σ_L为垂直于 x轴的正应力. 在线弹性条件下，将当量应力与热点应力的比例关系表示为

$$\sigma_{eq}=K_f\sigma_H \quad (3)$$

式中：σ_H为热点应力. 若当量应力 σ_{eq}等于磨平余高的对接焊试件的疲劳强度时，σ_H就是热点应力表示的接头疲劳强度. 因此，式 (3)的 K_f可理解为热点应力作为控制应力的疲劳切口系数，反映了局部应力集中对接头疲劳性能的影响程度.

应力集中、残余应力和疲劳荷载循环特征等是影响焊接接头疲劳行为的主要因素，其中，应力集中的效应最为显著[10]，它与结构整体几何形状、焊缝局部几何形状以及焊接缺陷等有关. 在一定程度上，由热点应力表述的焊接接头疲劳强度的分散度主要与局部应力集中程度的分散性有关，由于问题的复杂性，目前在理论上还缺乏有效的预测模型. 下面考察热点应力的确定方式、焊缝局部几何尺寸、主板厚度以及接头类型等因素对疲劳切口系数的影响.

2 计算结果讨论

考虑 T形、十字型这两类角焊缝接头与具有对接焊缝的对接接头，其几何参数、加载条件如图 3所示. 取某种低合金钢的材料参数，$\sigma_{-1}=245$ MPa，$\Delta K_{th}=294$ N/mm$^{3/2}$，则由式 (1)得临界距离参数 $a=0.36$ mm.

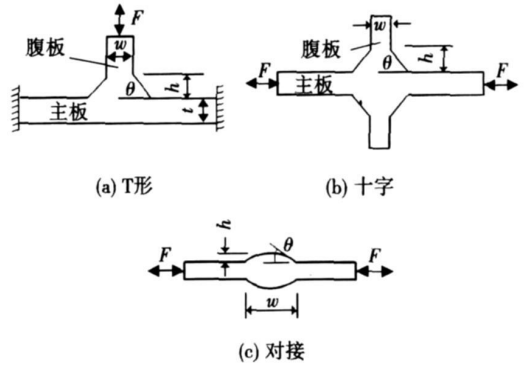

图 3 三类接头示意图

Fig. 3 Schematic of three types of joints

注意到对称性，取这三类接头进行平面应变有限元分析，热点部位的有限元网格尺寸小于 0.05 mm[7]. 首先，分别按前面三种热点应力的确定方法得到热点应力，针对十字接头和对接接头，这三种方法确定的热点应力实际上就是受力主板上的平均应力，后者也可理解为传统的名义应力. 然后由式 (2)进行数值积分得到当量应力，以确定疲劳切口系数.

T形和十字形接头的 K_f随腹板厚度的变化如图 4所示，其中，T形接头的主板厚度 $t=10$ mm，十字接头的 $t=6$ mm，焊高 h与腹板厚度 w相等，焊角 $\theta=45°$. 可见，相应于每一种热点应力确定方式，两类角焊缝接头的疲劳切口系数都在 5%范围内变化，表明其分散性受腹板厚度、焊缝高度、焊脚长度的影响小；在 T形接头中，对应于相同荷载与几何参数条件，依第二种方法确定的热点应力最大，第一种方法略小，第三种方法最小，故疲劳切口系数的值则正好相反. 基于两种外推方法给出的两组值较为接近，相对差值在 5%以内.

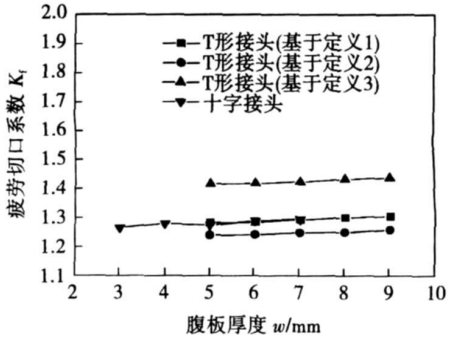

图 4 疲劳切口系数随腹板厚度的变化

Fig. 4 Fatigue notch factor vs thickness of web plate

图 5给出了 T形接头、十字接头和对接接头的 K_f随焊趾角的变化趋势,其中, T形接头的 $t=10$ mm, $h=w=8$ mm;十字接头的 $t=6$ mm, $h=w=4$ mm;对接接头 $t_b=10$ mm, $h=t_b/3$.从图 5可见,焊趾角在 40°~60°内变化时,角焊缝接头的 K_f差值在 5%内,相应于同一角度,基于两种外推方法确定热点应力得到的 K_f的差值也在 5%内;当焊趾角从 20°增加到 45°时,对接接头 K_f的值增大,但变化范围不超过 10%.综合以上讨论可知:对应于每一种热点应力的确定方法,腹板厚度与焊缝尺寸的改变引起的疲劳切口系数的分散性都不明显,且基于两种外推方法确定热点应力得到的 K_f值差别较小.

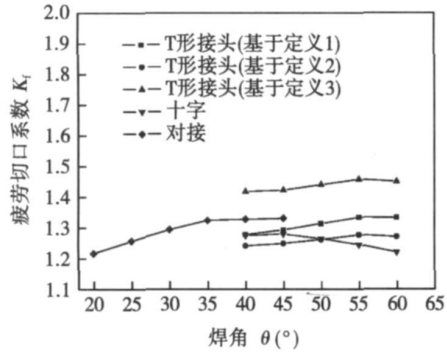

图 5　疲劳切口系数随焊趾角的改变

Fig. 5　Fatigue notch factor vs weld toe angle

主板厚度对 T形与十字接头的疲劳切口系数的影响见图 6,接头的几何参数取为 $w=2t/3$, $\theta=45°$,焊缝高度小于腹板厚度,且任意选定.由图 6可见,两类接头的 K_f值随主板厚度增加而变大.采用外推法确定热点应力时,同为角焊缝接头的 T形与十字形接头的 K_f呈现相同变化趋势,且对同一主板厚度,两者的值是接近的.而基于第三种热点应力确定方法得到的 K_f出现了不同的变化模式.这

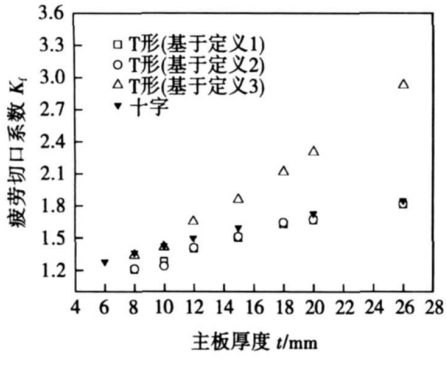

图 6　疲劳切口系数随主板厚度的变化的改变

Fig. 6　Fatigue notch factor vs thickness of main plate

说明依外推确定热点应力的方法比由单点确定热点应力的方式好,因为前者可使疲劳切口系数的分散性明显降低,从而使疲劳数据对焊接接头类型与荷载方式的依赖性减小.

采用 IIW推荐的外推方法确定热点应力,将 T形和十字形接头的 K_f与主板厚度的关系拟合,结果见图 7.图中同时给出对接接头的相关结果,其尺寸参数为 $h=t/3$, $\theta=30°$.从图 7可见,对应于较小的主板厚度 t,角焊缝接头与对接焊接头的 K_f值接近;而随着 t的增加,两者的 K_f值差别变大.拟合关系可表示为幂函数形式

$$K_f=\beta t^n \tag{4}$$

式中:β与 n为拟合参数,角焊缝与对接焊缝接头的 β分别为 0.7194与 0.8231; n分别为 0.2843和 0.1968.

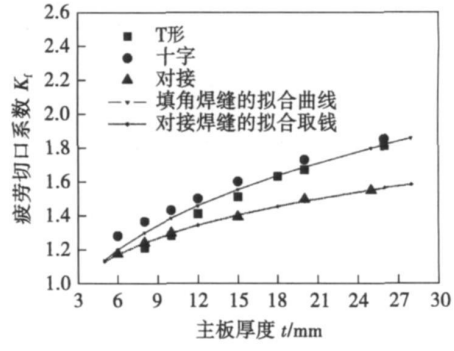

图 7　疲劳强度的厚度效应

Fig. 7　Effect of plate thickness on fatigue strength

焊接接头是焊缝金属、热影响区和母材金属共存的复杂缺口构件,可以认为其疲劳强度是与疲劳切口系数成反比[11].由式 (4)可分别得到角焊缝接头和对接焊接头的板厚效应预测公式

$$\sigma_H^{(1)}/\sigma_H^{(2)}=(t_2/t_1)^n \tag{5}$$

式中:$\sigma_H^{(1)}$和 $\sigma_H^{(2)}$表示主板厚度分别为 t_1和 t_2时接头的疲劳强度.基于试验数据整理出的 n值分别为角焊缝 0.3;对接焊 0.2[10],这些结果由 IIW推荐.可见理论预测得到的 n与实际结果是相当吻合的.

3　结　　论

(1)腹板厚度与焊缝尺寸对疲劳切口系数的影响较小,但主板厚度的影响大,当由外推法确定热点应力时,根据疲劳切口系数得到的角焊缝接头和对接焊缝接头的板厚效应预测与试验结果很接近,而且,基于两种外推方法得到的疲劳切口系数相差小.

(2)从疲劳切口系数分散性较小这一角度来考

虑,基于外推法确定热点应力的疲劳评定法能明显减少疲劳数据的分散度以及对接头类型与载荷形式的依赖性.

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作者简介: 彭 凡, 男, 1963年出生, 博士, 教授. 主要研究方向为结构疲劳与断裂、复合材料力学. 发表论文 40余篇.

Email: pengfan_1989@yahoo.com.cn

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作者简介: 李 果, 女, 1985年出生, 硕士研究生. 主要研究过程装备先进制造技术.

Email: liguoperfect@163.com

ing systems in welding robot the camera model in Open Source Computer Vision Library(OpenCV) was discussed a profound investigation of the camera calibration process and geometric model was performed Specially the radial distortion and tangential distortion had been taken into account Then the Bouguet corner point s extraction algorithm was applied and a camera calibration algorithm based on OpenCV was implemented The results show that the algorithm gives full play of the functions in OpenCV library and extracts the checkboard corners successfully both the precision and computational efficiency are improved Therefore it can satisfy the requirements of real-time performance in camera calibration of vision navigation system.

Key words: seam tracking; vision guidance; camera calibration; OpenCV; planar template

Finite element analysis and nanoindentation-based experiment of residual stress of SS304/BNi-2/SS304 stainless steel brazed joints LI Guo1, GONG Jianming1, CHEN Hu2 (1. School of Mechanical and Power Engineering, Nanjing University of Technology, Nanjing 210009, China; 2. Technical Development Department, Ningbo Special Equipment Inspection and Test Center, Ningbo 315020, Zhejiang, China). p79—82, 86

Abstract: The numerical analysis was implemented on the residual stress of the SS304/BNi-2/SS304 T shape brazed joint by both finite element method (FEM) employing ABAQUS sequentially coupling code and Nanoindentation technology. The results show that the residual stress of the brazed joint produced due to the mechanical property mismatch of the base metal SS304 and the filler BNi-2. The residual stress which can induce the crack initiation and is maximum at the fillet and decreases gradually along the mid-seaming. The other zone is uniformity. So the fillet becomes the weakest area. The Nanoindentation test adopts the Suresh model and the experimental results are corresponded with the FEM and also prove the efficient and reliability of FEM.

Key words: brazing; nanoindentation; residual stress; finite element; T shape joint

Influence factors of fatigue strength assessment for welded joints by hot spot stress approach PENG Fan, YAO Yunjian, GU Yongjun (College of Mechanical and Vehicle Engineering, Hunan University, Changsha 410082, China). p83—86

Abstract: The fatigue notch factors of welded joints are expressed in terms of hot spot stress serving as controlling stress and obtained on the basis of Taylor's Critical Distance Theory corresponding to three approaches to determine hot spot stress. The effects of joint types, weld sizes, main plate thickness and the methods to determine the hot spot stresses on the fatigue assessment of welded joints are examined with the analysis of fatigue notch factors. The results show that the influence of weld size and the web plate thickness on the scatter of fatigue notch factors is small in contrary to the obvious effect of the main plate thickness, and the latter is predicted for welded joints of fillet welds and butt welds respectively by means of fatigue notch factors and is found to be in good agreement with existing empirical relation. Also it is indicated that the two types of extrapolation method to obtain hot spot stresses are valid in reducing the diversity of fatigue data and the dependence of fatigue data on the types of joints and loading conditions.

Key words: welded joints; fatigue strength; hot spot stress; critic distances theory; fatigue notch factor

Effect of magnetic field on twin-wire indirect arc shape ZHANG Shunshan, WU Dongting, ZOU Zengda, QU Shiyao (Key Laboratory for Liquid-Solid Structural Evolution & Processing of Materials, Ministry of Education, Shandong University, Jinan 250061, China). p87—90

Abstract: The effect of internal magnetic field and external magnetic field on twin-wire indirect arc shape was studied in this paper. The variation of internal magnetic field was obtained by changing the angle of wires. The external magnetic field was applied by excitation coil. The magnetic induction intensity was measured by Teslameter, and the indirect arc shapes were captured by high-speed camera system. The experimental results showed that the magnetic intensity difference between the internal and external region of arc increased by decreasing of the included angle and increasing of applied transverse external magnetic intensity. As a result, which increased the extrapolation effect of electromagnetic force and the arc became long and concentrated. Applied longitudinal external magnetic field would deflect the indirect arc in the vertical plane of the twin wires, and the deflection degree increased with increasing of applied longitudinal external magnetic intensity.

Key words: twin wires welding; indirect arc; arc shape

Mathematical model for NC cutting saddle type of welding groove with edge CHEN Yongliu, BAI Xue (School of Mechanical & Power Engineering, Harbin University of Science and Technology, Harbin 150080, China). p91—94

Abstract: This paper is based on the establisment of the mathematics model for saddle type welding groove with the edge, given the geometric definition of the edge curves, the influence of the different cutting tracks to the principle error Δb of the height of the edge was discussed. The length change Δm of groove generatrix has an effect on the distance a between cutting torch and workpiece, the eliminate method that the existence of Δm which causes the distance between cutting torch and workpiece changes Δa is introduced. The establisment of the mathematical model for saddle type welding groove with the edge by the welding groove geometric model to calculate the Δm and set the method of Δm and cutting intersection angle θ curves is descriked. It concluse that using the edge curves as the cutting tracks can eliminate the change of Δa caused by the Δm and improve the cutting quality and accuracy.

Key words: welding; NC cutting; intersecting line; welding groove; saddle type; mathematics model

Segment-moving heat source model with strip-shape and combined distribution of heat flux ZHENG Zhentai,