DOI:10.15986/j.1006-7930.2011.05.006

第43卷 第5期 西安建筑科技大学学报(自然科学版) Vol.43 No.5
2011年10月 J. Xi′an Univ. of Arch. & Tech. (Natural Science Edition) Oct. 2011

建筑钢结构熔透对接焊缝缺陷对焊缝抗拉承载力影响的研究

杨晓东[1,2],雷艳春[3],尚建丽[1,2],岳 鹏[1,2,4]

(1.西安建筑科技大学材料科学与工程学院 陕西 西安 710055; 2 西部建筑科技国家重点实验室(筹),陕西 西安 710055; 3 西安工业大学建筑工程学院,陕西 西安 710032; 4 西安建筑科技大学建筑学院,陕西 西安 710055)

摘 要:超声波探伤计算建筑钢结构熔透对接焊缝的缺陷率,对含有不同位置缺陷及缺陷率的焊缝进行拉力试验,用缺陷率-焊缝强度关系图分析焊缝抗拉承载力达到:母材强度,GB50017-2003 一、二、三级熔透对接焊缝设计值,母材屈服强度标准值时,建筑钢结构熔透对接焊缝可允许存在的体积性缺陷率限值.研究结果表明:存在于熔透对接焊缝中部的缺陷,当缺陷率小于2.6%时,焊缝的抗拉强度大于母材的强度,当缺陷率小于8.0%时,焊缝的抗拉强度大于母材屈服强度标准值,当缺陷率小于25.5%时,焊缝的抗拉强度大于GB50017-2003 一、二级熔透对接焊缝设计值,当缺陷率小于30.0%时,焊缝的抗拉强度大于GB50017-2003 三级熔透对接焊缝设计值;存在于熔透对接焊缝根部的缺陷,当缺陷率小于11.0%时,焊缝的抗拉强度大于母材屈服强度标准值以及GB50017-2003 一、二级熔透对接焊缝设计值,当缺陷率小于23.0%时,焊缝的抗拉强度大于GB50017-2003 三级熔透对接焊缝设计值.

关键词:建筑钢结构;熔透对接焊;焊缝抗拉承载力;焊接缺陷;缺陷率限值

中图分类号:TB441 7 文献标志码:A 文章编号:1006-7930(2011)05-0730-05

建筑钢结构现场焊接,焊缝中的缺陷不可避免.国际上公认的焊缝中可以存在一些"体积性"缺陷(缺陷尺寸可进行三维度量),然而国内外对焊接缺陷的研究主要集中在造船、压力容器等行业[1],对于建筑钢结构焊接体积性缺陷的大小与结构正常使用之间的相关性尚需研究.

建筑钢结构焊缝与锅炉压力容器等封闭性钢结构焊缝受力状况有着本质的区别,焊缝在建筑钢结构中所处的位置不同,承受荷载大小、种类也不相同,破坏后产生的危害程度也不相同,因此对焊缝质量的要求也应不一样,如果一味的追求消除焊接缺陷要求,将造成不必要的浪费.

1 材料及试验

1.1 钢材

试验用钢材:Q345B,厚度为10 mm、12 mm、16 mm、18 mm、20 mm、22 mm.《低合金高强度结构钢》GB/T1591-2008 规定Q345B材质的力学指标及试验钢材的力学性能实测值如表1所示.

表1 钢材的力学性能

Tab. 1 Mechanical property of the steel

Type		Yield strength /MPa	Ultimate tensile strength /MPa	Elongation rate after break /%
Testing value		380~400	482~556	29.0~33.0
Standard value in code	≤16 mm	345	470~630	≥20
	>16~40 mm	335		

1.2 焊材和试件

焊条型号为E5003,焊条的力学性能如表2所示;焊缝试件为熔透对接形式,焊接方式为手工电弧

*收稿日期:2011-03-02 修改稿日期:2011-07-26

基金项目:陕西省教育厅自然科学专项(09JK558)

作者简介:杨晓东(1968-),男,陕西勉县人,高级工程师,主要从事钢结构无损探伤的研究工作.

焊, 试件宽度为 50 mm;《钢结构设计规范》GB50017-2003 中规定的焊缝设计强度[2] 如表 3 所示.

表 2　E5003 焊条力学性能

Tab. 2　Mechanical property of welding electrode

Type	Yield strength / MPa	Ultimate tensile strength / MPa	Elongation after break / %
E5003	430	560	25

表 3　熔透对接焊缝设计强度

Tab. 3　Design strength of penetrated butt weld

Type of steel	Thickness of steel slab/ mm	Compressive strength / MPa	Tensile strength/ MPa		Shear strength / MPa
			Grade 1, grade 2	Grade 3	
Q345B	≤16	310	310	265	180
	16~40	295	295	250	175

1.3　试验设备

(1)试件测试仪器: WE—1000A(立式)万能材料试验机, 最大量程为 0~1 000 kN, 一级精度.

(2)试验加荷速度: 试验加荷载应力速率为: 2 ~20 MPa/s.

1.4　熔透对接焊缝缺陷率的表达

存在于熔透对接焊缝中的"体积性"缺陷, 用超声波探伤确定其当量孔径(或高度)及指示长度, 缺陷位置有焊缝根部和焊缝中部, 但无论何种位置的"体积性"缺陷存在于焊缝中, 结果都使焊缝的有效截面积减小, 所以计算缺陷当量时, 将缺陷当量都简化为与焊缝截面平行的最大面积, 如图 1 所示. 熔透对接焊缺陷率(P), 用缺陷当量总和(S_q)占缺陷处焊缝总截面积(S)的百分数表示(S_q/S).

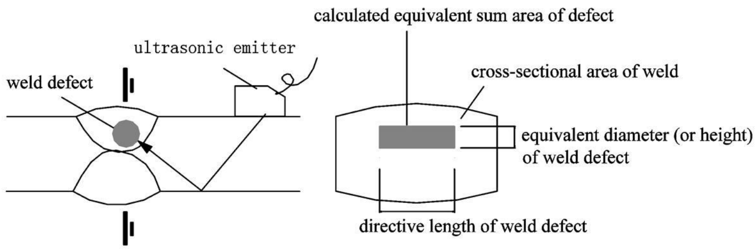

图 1　缺陷率计算示意图

Fig. 1　Schematic diagram of defect rate

2　熔透对接焊缝缺陷对焊缝抗拉承载力的影响

2.1　含中部缺陷焊缝抗拉试验, 测试结果见表 **4**.

表 4　焊接时产生中部缺陷的焊缝抗拉测试结果

Tab. 4　Tensile test result of specimens with defects amidst welding

Specimen	Thickness/mm	Ultimate tensile strength R/MPa	Defect rate P/%	Position of crack	The type of steel slab
1	16	519	2.7	steel slab	Q345B
2	16	556	2.6	steel slab	Q345B
3	16	553	1.6	steel slab	Q345B
4	16	422	4.5	weld	Q345B
5	16	332	29.7	weld	Q345B
6	16	243	30.1	weld	Q345B
7	16	320	15.4	weld	Q345B
8	10	293	26.1	weld	Q345B
9	10	421	7.5	weld	Q345B
10	10	339	8.5	weld	Q345B
11	10	538	0.33	steel slab	Q345B
12	20	533	2.8	steel slab	Q345B
13	20	545	2.5	steel slab	Q345B
14	20	505	6.2	weld	Q345B
15	20	516	5.1	weld	Q345B
16	20	235	35.0	weld	Q345B
17	20	340	17.5	weld	Q345B
18	22	305	25.5	weld	Q345B
19	22	430	7.0	weld	Q345B
20	22	325	9.6	weld	Q345B
21	22	550	1.9	steel slab	Q345B

对表4数据分析,见图2、3所示.

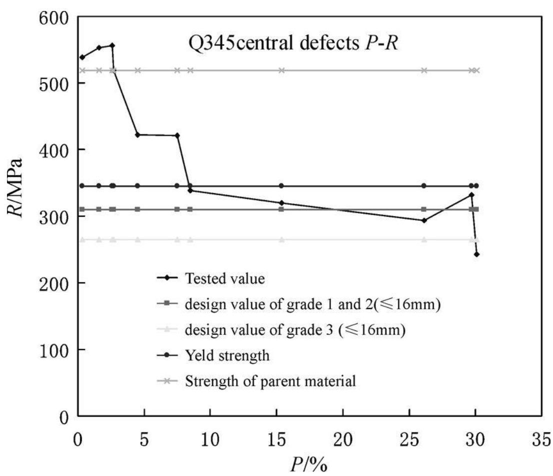

图2 不大于16 mm厚钢板焊缝焊接中部缺陷—焊缝抗拉强度分析图

Fig. 2 Analysis on the tensile strength of weld with central defects in specimens with thickness of not more than 16 mm

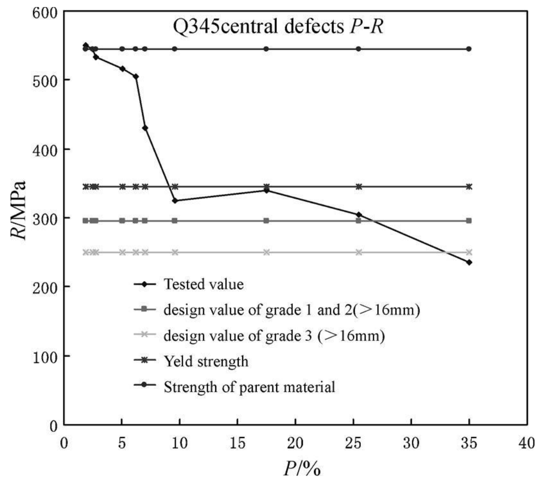

图3 大于16 mm厚钢板焊缝焊接中部缺陷—焊缝抗拉强度分析图

Fig. 3 Analysis on the tensile strength of weld with central defects in specimens with thickness of greater than 16 mm

从图2看,不大于16 mm板厚Q345B钢板熔透对接焊缝中部缺陷率小于2.7%,焊缝的抗拉强度大于母材强度;中部缺陷率小于20.0%,焊缝的抗拉强度大于GB50017-2003一、二级熔透对接焊缝设计值;中部缺陷率小于30.0%,焊缝的抗拉强度大于GB50017-2003三级熔透对接焊缝设计值;中部缺陷率小于8.0%,焊缝的抗拉强度大于钢板屈服强度标准.

从图3看,大于16 mm板厚Q345B钢板熔透对接焊缝中部缺陷小于2.6%,焊缝的抗拉强度大于母材强度;中部缺陷率小于26.0%,焊缝的抗拉强度大于GB50017-2003一、二级熔透对接焊缝设计值;中部缺陷率小于32.5%,焊缝的抗拉强度大于GB50017-2003三级熔透对接焊缝设计值;中部缺陷率小于9.0%,焊缝的抗拉强度大于钢板屈服强度标准.

2.2 焊接过程中形成根部缺陷的熔透对接焊缝抗拉试验,测试结果见表**5**.

表**5** 焊接过程产生根部缺陷的焊缝抗拉测试结果

Tab. 5 Tensile test result of specimens with defects in weld root

Specimen	Thickness/mm	Ultimate tensile strength R/MPa	Defect rate P/%	Position of crack	The type of steel slab
1	12	286	17.4	steel	Q345B
2	12	279	11.7	steel	Q345B
3	12	390	11.4	steel	Q345B
4	12	482	3.1	steel slab	Q345B
5	18	156	57.5	steel	Q345B
6	18	184	30.6	steel	Q345B
7	18	402	4.7	steel	Q345B
8	18	320	6.8	steel	Q345B
9	18	256	11.5	steel	Q345B
10	20	179	35.2	steel	Q345B
11	20	141	51.1	steel	Q345B
12	20	148	65.7	steel	Q345B
13	20	417	2.03	steel	Q345B
14	20	436	10.5	steel	Q345B
15	20	340	12.6	steel	Q345B
16	16	431	0.6	steel	Q345B
17	16	406	5.4	steel	Q345B
18	16	378	11.6	steel	Q345B
19	16	208	47.3	steel	Q345B
20	16	158	52.2	steel	Q345B

对表 5 测试数据分析, 见图 4、5 所示.

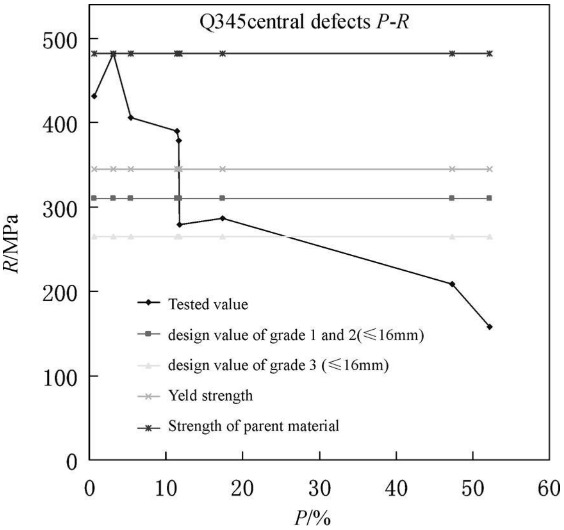

图 4　不大于 16 mm 厚钢板焊缝焊接根部缺陷—抗拉强度分析图

Fig. 4　Analysis on the tensile strength of weld with root defects in specimens with thickness of not more than 16 mm

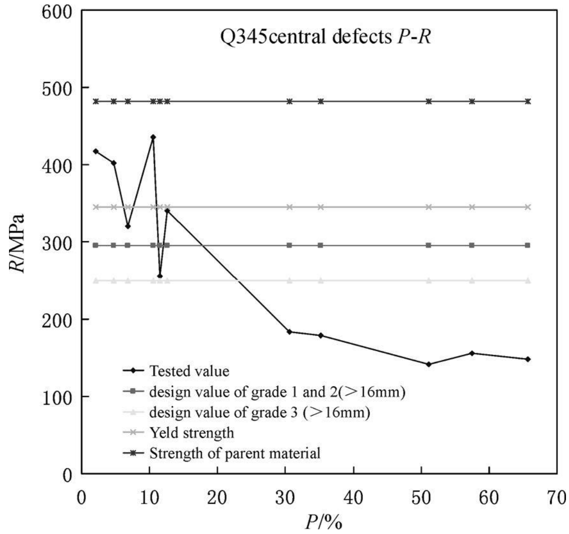

图 5　大于 16 mm 厚钢板焊缝焊接根部缺陷—抗拉强度分析图

Fig. 5　Analysis on the tensile strength of weld with root defects in specimens with thickness of greater than 16 mm

从图 4、5 看, 焊接过程形成的根部缺陷对于焊缝是否能达到母材抗拉强度影响较大, 实验数据表明很小的根部缺陷率(16 mm 厚钢板, $P=0.6\%$; 20 mm 厚钢板, $P=2.03\%$)也能导致焊缝抗拉强度低于母材抗拉强度(这是因为在高温下产生根部开口缺陷, 再经过冷却, 缺陷内外变形不一致, 容易向里面形成尖端——裂尖, 当焊缝受拉, 尖端处将形成较高的应力, 导致焊缝迅速破裂); 缺陷率达 11.0%左右时, 根部缺陷会引起焊缝抗拉强度几乎垂直突变性的降低, 焊缝抗拉强度几乎同时低于 GB50017-2003 一、二级熔透焊设计值和钢板屈服强度标准; 不大于 16 mm 厚的钢板, 缺陷率达到 25%左右时, 焊缝抗拉强度低于 GB50017-2003 三级熔透焊设计值; 大于 16 mm 厚的钢板, 缺陷率达到 23%左右时, 焊缝抗拉强度低于 GB50017-2003 三级熔透焊设计值.

3　结　论

熔透对接焊缝抗拉承载力分别达到不同的强度级别时, 超声波探伤确定的最大体积性缺陷率限值, 见表 6 所示.

表 **6**　焊缝抗拉承载力分别达到不同的强度, 最大体积性缺陷率限值

Tab. 6　Maximum limits of defect rate in penetrated butt weld satisfied with different bearing capacity

type of defect	Tensile capacity			
	≥tensile strength of base steel	≥standard yield strength	≥design value of grade 1 and 2	≥design value of grade 3
Defects in central/ %	2.6	8.0	25.5	30.0
Defects at root/ %	0	11.0	11.0	23.0

熔透对接焊缝抗拉承载力: 中部缺陷, 缺陷率小于 2.6%时, 其抗拉强度大于母材的强度, 缺陷率小于 8.0%时, 其抗拉强度大于母材屈服强度标准值, 当缺陷率小于 25.5%时, 其抗拉强度大于 GB50017-2003 一、二级熔透对接焊缝设计值, 当缺陷率小于 30.0%时, 其抗拉强度大于 GB50017-2003 三级熔透对接焊缝设计值; 焊缝根部存在缺陷, 其强度均低于母材强度, 当缺陷率小于 11.0%时, 其抗拉强度大于母材屈服强度标准值以及 GB50017-2003 一、二级熔透对接焊缝设计值, 当缺陷率小于 23.0%时, 其抗拉强度大于 GB50017-2003 三级熔透对接焊缝设计值.

参考文献 References

[1] 孟广喆. 焊接结构强度和断裂[M]. 北京: 机械工业出版社, 1986: 498-500.
MENG Guang-zhe. Strength and Fracture of Welded Structure[M]. Beijing: China Machine Press, 1986: 498-500.

[2] GB50017-2003, 钢结构设计规范[S]. 北京: 中国计划出版社, 2003: 18.
GB50017-2003, Design Code for Steel Structure[S]. Beijing: China Planning Press, 2003: 18.

[3] 张宝昌. 焊接结构安全评定技术[M]. 北京: 机械工业出版社, 1990.
ZHANG Bao-chang. Safety Assessment of Technology of Welded Structure[M]. Beijing: Mechanical Industry Press, 1990.

[4] 全国锅炉压力容器无损检测人员资格考核委员会. 超声波探伤[M]. 北京: 中国锅炉压力容器安全杂志社, 1995.
National Personnel Qualification and Evaluation Commission on Boiler and Pressure Vessel NDT. Ultrasonic Testing[M]. Beijing: China Boiler and Pressure Vessel Safety magazine, 1995.

[5] 杨晓东, 尚建丽, 刘 北. AutoCAD智能技术在焊缝超声波探伤中的应用[J]. 工业建筑, 2006, 34(411): 512-513.
YANG Xiao-dong, SHANG Jian-li, LIU Bei. AutoCAD Smart Technology in Ultrasonic Testing of Welds[J]. Industrial Construction, 2006, 34(411): 512-513.

[6] 钢焊缝手工超声波探伤方法和探伤结果的分级[M]. 北京: 劳动部锅炉压力容器安全杂志社, 1989.
Manual Ultrasonic Testing Methods of Steel Welds and classification of testing results[M]. Beijing: Ministry of Labour boiler and pressure vessel safety magazine, 1989.

[7] 陈冰泉. 船舶及海洋工程结构焊接[M]. 北京: 人民交通出版社, 2001.
CHEN Bing-quan. Structural Welding in Ships and Ocean Engineering[M]. Beijing: China Communications Press, 2001.

[8] 杨晓东, 刘 北, 尚建丽, 等. 关于GB50205-2001焊缝探伤探讨[J]. 建筑技术, 2008, 39(5): 390-392.
YANG Xiao-dong, LIU Bei, SHANG Jian-li, et al. Discuss on Ultrasonic Testing of Weld Defects in GB50205-2001[J]. Building Technology, 2008, 39(5): 390-392.

Study on the influence of penetrated butt weld defects on weld tensile bearing capacity

YANG Xiao-dong[1,2], *LEI Yan-chun*[3], *SHANG Jian-li*[1,2], *YUE Peng*[1,2,4]

(1. School of Material Science and Engineering, Xi′an University of Architecture and Technology, Xi′an, 710055, China;
2. State Key Laboratory of Architeeture Science & Technology in West Chine (XAUAT), Xi′an 710055, China;
3. Department of Civil Engineering and Architecture, Xi′an Technological University, Xi′an 710032, China;
4. School of Architecture, Xi′an University of Architecture and Technology, Xi′an 710055, China)

Abstract: In this paper the construction steel structure penetration butt weld defects are calculated through ultrasonic testing and tension tests are made for welds containing defects in different positions. By the defect-weld strength relationship chart, the acceptable volume defect limits are analyzed when the weld tensile bearing capacity achieves mother materials strength, GB50017-2003 first, second and third penetration butt weld design value, yield strength of mother materials standard, respectively. In penetration butt welding, the results show that the central weld defect is less than 2.6%, the weld tensile bearing capacity is greater than the mother materials strength. If the defect is less than 8.0%, the weld tensile bearing capacity is greater than yield strength of mother materials standard and if the central weld defects is less than 25.5%, the weld tensile bearing capacity is greater than design value of Grade 1 and 2. When the central weld defects is less than 30%, the weld tensile bearing capacity is greater than the design value of Grade 3. In penetration butt welding root defect, if the defect is less than 11%, the weld tensile bearing capacity is greater than the yield strength of mother materials standard or design value of Grade 1 and 2, and if the defect is less than 23.0%, the weld tensile bearing capacity is greater than the design value of grade 3.

Key words: *construction steel structure; penetration butt welding; weld tensile bearing capacity; welding defects; defects limits*

Biography: YANG Xiao-dong, Senior Engineer, Xi′an 710055, P. R. China, Tel: 0086-29-82205649, E-mail: yxd681125@126.com