第33卷 第4期 焊 接 学 报 Vol. 33 No. 4
2012年4月 TRANSACTIONS OF THE CHINA WELDING INSTITUTION April 2012

铝合金薄板激光拼焊工艺及其杯突成形性能

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摘 要： 主要研究6061铝合金激光拼焊板的工艺及成形性能，分析拼焊板在杯突试验中的成形特点以及焊缝对拼焊板的整体塑性成形的影响. 杯突成形性能试验结果显示了宏观开裂发生在稍偏移焊缝中心的狭窄热影响区内；拼焊板试验杯突值低于母材杯突值；基于DYNAFORM软件数值模拟，忽略焊缝类型，仅考虑焊缝在板材上的位置. 结果表明，拼焊板杯突模拟开裂容易发生在杯突顶端下沿的焊缝处，模拟结果与实际试验结果略有差异，这可能与焊缝设置有一定关系.

关键词： 6061铝合金薄板；激光拼焊；杯突成形；DYNAFORM模拟

中图分类号： TG456.7 **文献标识码：** A **文章编号：** 0253－360X(2012)04－0081－04

0 序 言

随着汽车制造业的发展，铝及铝合金以其密度小、弹性好、耐蚀性好、比强度和比刚度较高、抗冲击性能好等一系列优良特性在汽车行业得到越来越广泛的应用. 同时作为顺应汽车工业发展潮流的激光拼焊技术，以其节约材料、减轻车重、降低成本、提高安全性等优点成为一种先进的制造技术. 因此研究高性能的汽车用铝合金拼焊板工艺及成形性能对提高国内汽车行业在国际中的竞争力具有举足轻重的作用，与此同时将产生一定的经济效益和社会效益[1,2].

杯突试验融合了拉深与胀形的工艺特点[3,4]，是检测板材塑性成形性能、焊接接头质量的工艺性能试验之一，在给定的试样条件下可以测试金属板材对胀形拉深变形的适应极限. 文中对1 mm厚6061铝合金激光拼焊板进行杯突测试，分析与研究拼焊板在杯突试验中的成形特点以及焊缝对拼焊板的整体塑性成形的影响. 最后选用DYNAFORM软件对铝合金激光拼焊板的杯突成形试验过程进行数值仿真模拟研究与分析并与试验结果进行对比.

1 激光拼焊工艺

1.1 试验设计与结果

该试验选用的材料是1 mm厚6061铝合金板，其化学成分如表1所示.

表1 6061铝合金的化学成分(质量分数，%)

Table 1 Chemical compositions of 6061

Mg	Si	Cu	Cr	Fe
0.8～1.2	0.4～0.8	0.15～0.4	0.04～0.35	0.7
Mn	**Zn**	**Ti**	**Al**	
0.15	0.25	0.15	余量	

试验中采用砂纸打磨与表面涂抹活性剂相结合的方法对其进行表面处理，其表面活性剂自行设计. 将1 mm厚6061铝合金薄板制成200 mm×77 mm的试样，沿长度方向对两块板进行对接，焊接采用连续激光焊，试验中使用英国GSI公司JK2003SM型Nd:YAG固体激光器激光焊机. 获得较好焊接接头的铝合金拼焊板的激光焊接参数及形貌分别见表2和图1，由试验可知不加表面活性剂的拼焊板未焊透，表面活性剂对铝合金的焊接起重要作用.

表2 焊接工艺参数

Table 2 Parameters of welding procedure

试样编号	激光功率 P/W	焊接速度 v/(cm·min^{-1})	表面状态	离焦量 ΔF/mm
A	2 600	20	－	－0.2
B	1 700	40	＋	－0.2
C	1 900	20	＋	－0.2

注 “＋”添加表面活性剂 “－”不添加表面活性剂

收稿日期：2011－03－02

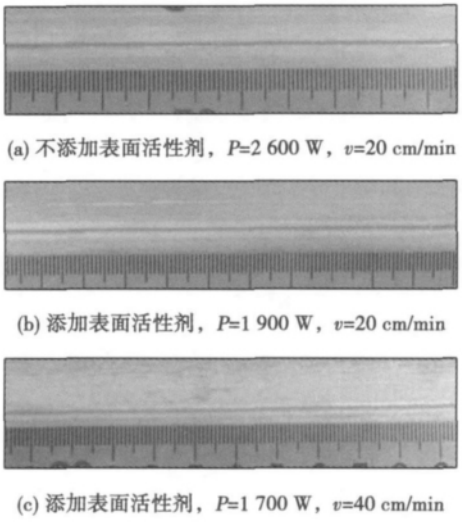

图 1 不同参数下的激光拼焊板宏观形貌

Fig. 1 TWB of LBW with different parameters

1.2 焊接接头显微组织测试

针对 B，C 两种工艺参数所得试样进行金相组织测试，测试结果如图 2 所示.

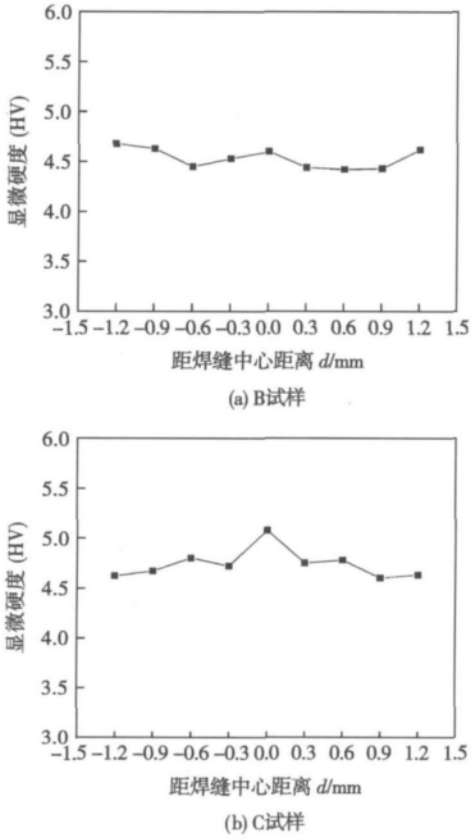

图 2 激光拼焊板焊接接头硬度分布

Fig. 2 Distribution of hardness of welded joint

从图 2 可以看到整个焊接接头的硬度与母材硬度相差不大，变化不明显，焊缝中心位置硬度与母材基本一致，甚至有些情况下会更高一些，但是在偏移焊缝的熔合区硬度值有所降低. 这是由于激光焊接的能量输入比较集中、焊缝窄、对母材影响较小、硬度值的变化范围相对较小. 焊缝中心过冷度大，结晶后晶粒得到细化，相比母材组织晶粒更细小、大小均匀、致密度高，从而保证了材料的硬度保持在较好的水平. 在熔合区，由于焊接过程容易产生气孔并且没有添加焊接材料使熔合区得到补充，可能造成该处硬度值降低. 合理的控制焊接工艺，特别是控制气孔的形成可以有效的控制硬度的变化. 随着远离焊缝中心距离的增加，硬度逐渐增加，直至达到母材硬度.

2 铝合金激光拼焊板的杯突试验

2.1 杯突试验设计

试验采用国家标准 GB4156—84 金属杯突试验方法，杯突深度测量标尺最小刻度为 0.1 mm. 对 B，C 两个工艺参数所得试样进行测试，每组数据分别取 3 个试样，最终试验结果取 3 组数据的平均值，试样编号见表 3.

表 3 杯突试样分类及编号

Table 3 Classification and numbering of cupping test specimens

编号	焊接功率 P/W	焊接速度 v/(cm·min^{-1})
B1	1 900	20
B2	1 900	20
B3	1 900	20
C1	1 700	40
C2	1 700	40
C3	1 700	40

2.2 杯突试验结果与分析

杯突试验数据如表 4 所示，试验结果如图 3 所示.

表 4 杯突试验数据

Table 4 Results of TWB cupping test

试样	杯突值 D_{IE}/mm	试样	杯突值 D_{IE}/mm
B1	9.30	C1	8.88
B2	8.94	C2	8.52
B3	9.11	C3	8.96
均值	9.12	均值	8.79

由表 4 中试验数据可知，与母材的杯突值相比，拼焊板的杯突值要低一些，说明焊缝区的胀形性能低于母材. 由图 3 可以看到，开裂多发生在稍偏移

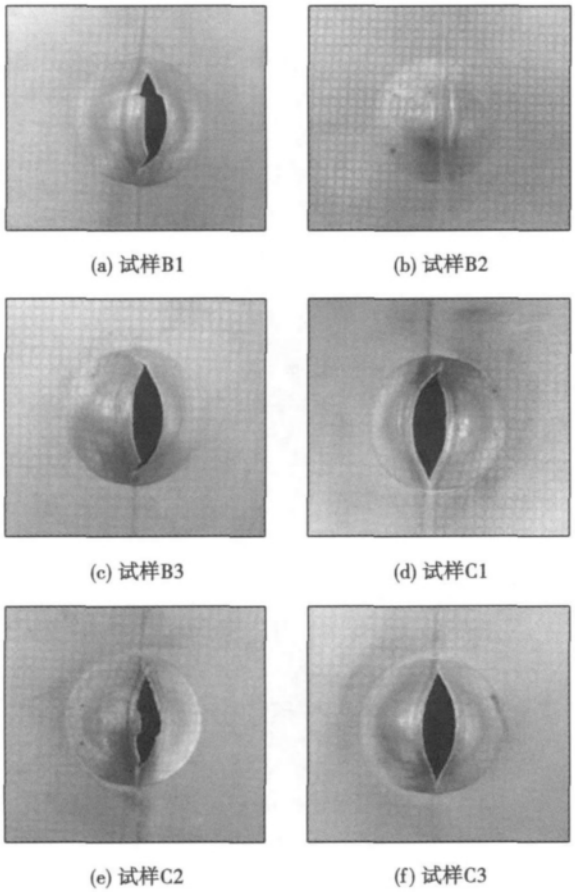

图 3　拼焊板杯突试验结果

Fig. 3　Results of TWB cupping test

焊缝中心的狭窄热影响区内，这是由于在焊接热循环的作用下，焊缝区内的部分晶粒有不同程度的长大，与母材晶粒相比，热影响区区域内的晶粒更粗大，降低了焊缝区部位的塑性和韧性，在杯突试验的深冲过程中容易产生裂纹导致开裂，这与焊接接头显微硬度测试的结果是一致的.

对比两组试验结果，杯突值没有明显的变化. 裂纹出现在偏移焊缝中心的狭窄热影响区内，拼焊板的杯突值低于母材的杯突值，说明焊缝区胀形性能低于母材，焊缝的质量很大程度上决定了 6061 铝合金拼焊板的冲压成形性能.

3　铝合金拼焊板的有限元模拟

基于 DYNAFORM 软件，先用 PRO/E 软件建立零件模型，然后导入 DYNAFORM 软件，对拼焊板坯料进行焊缝定义. 考虑到 1 mm 厚 6061 铝合金激光拼焊板的焊缝宽度较小，热影响区不明显，为了简化坯料模型，模拟试验中忽略焊缝类型[5] 只考虑焊缝在板材上的位置. 摩擦系数为 0.2，压边力为 10 kN，冲头速度为 5 000 mm/s、位移为 30 mm 时模拟试验结果如图 4 ~ 图 6 所示.

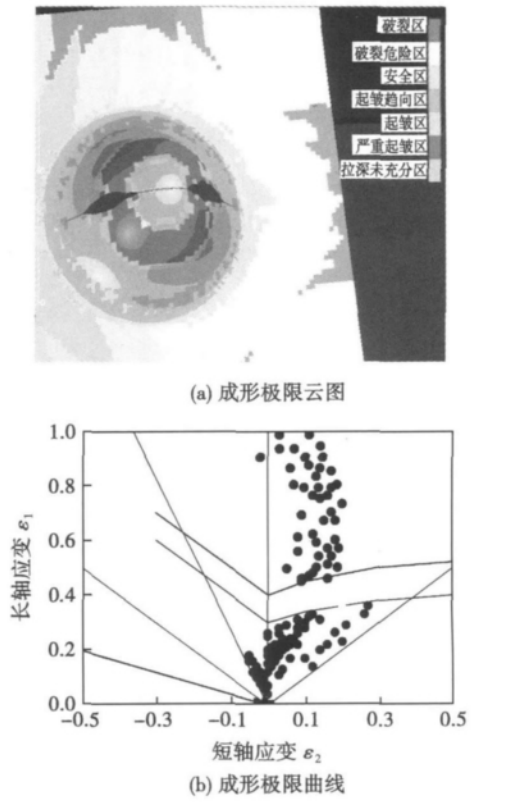

图 4　板料破裂成形极限

Fig. 4　Forming limit diagram of blanking cracked

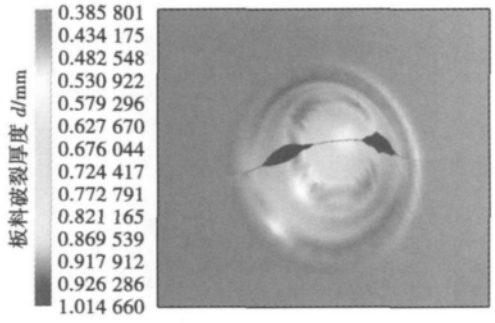

图 5　板料破裂厚度

Fig. 5　Thickness diagram of blanking cracked

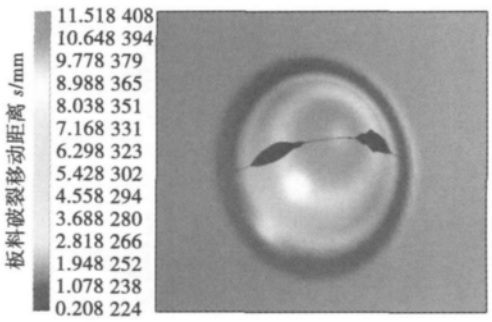

图 6　板料破裂移动距离

Fig. 6　Displacement diagram of blanking cracked

从图 4 中可以看到容易发生开裂的位置出现在杯突顶端下沿的红色危险区域内. 模拟试验建模时只考虑到焊缝在板材上的位置,而忽略了焊缝类型,致使模拟结果显示在红色危险区的焊缝处产生杯突裂纹,这与实际杯突测试结果稍有差别.

坯料厚度变化图 5 中可以看出,拼焊板厚度在杯突模拟试验中的变化相对比较均匀,这是由于虽然焊缝的存在对试验的过程有所影响,但是由于焊缝比较窄,模拟过程中板材的塑性变形主要受母材的影响,从而表现为厚度变化相对比较均匀.

根据图 6 中试验数据可以看出,拼焊板的模拟试验杯突值要低于母材的模拟试验杯突值,这与实际杯突试验结果一致. 说明焊缝的存在确实影响了拼焊板的胀形性能,使得拼焊板的胀形性能低于母材.

4 结 论

(1) 铝合金的焊接工艺参数可知,在平均功率 1 700 ~ 1 900 W,焊接速度 20 cm/min 时焊接接头较好且表面活性剂的作用很大.

(2) 铝合金激光拼焊板杯突成形性能试验结果显示开裂容易发生在稍偏移焊缝中心的狭窄热影响区内,拼焊板试验杯突值低于母材杯突值,表明该试验拼焊板的胀形性低于母材.

(3) 忽略焊缝类型,只考虑焊缝在板材上的位置,DYNAFORM 软件数值模拟结果显示,受焊缝影响,拼焊板杯突模拟开裂容易发生在杯突顶端下沿的焊缝处,模拟结果与实际试验结果略有差异,这与焊缝设置有一定关系.

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number of needle-like and thread-like tin whiskers were formed on the surface of the oxidized RE phases. It was noteworthy to mention that these tin whiskers kept the constant cross section during growth process. However, besides these regular tin whiskers, some new ones with special morphology, such as lapped whiskers, branch and combination of whiskers, were also found.

Key words: rare earth phase; aging; tin whisker; morphology

Fracture toughness of square drill pipe joint by narrow gap welding MA Caixia[1], ZHANG Se[2], HUANG Xusheng[2], LIN Chengxiao[1], MA Fubao[2], YANG Siqian[1] (1. Shanxi Key Laboratory of Friction Welding Technologies, Northwestern Polytechnical University, Xi'an 710072, China; 2. Shanxi Northfenglei Industrial Group Co., Ltd., Houma 043013, China). pp 77 - 80

Abstract: The test and calculation methods for the dynamic fracture toughness of 40CrMnMo square drill pipe joint produced by narrow gap pulsed metal arc welding were studied. Combined with the use of square drill pipe, pipe size and welding characteristics, the repeated impact 3-point bending test was used to test the fracture toughness of the square drill pipe joint. The crack depth was measured by using a microscope. and K_{Id} values were calculated with a FORTRAN program. The experimental results show that K_{Id} of the weld is 96% of that of the base material, but K_{Id} of the fusion line is only 89% of that of the base material. The analyses on the fracture surface and cross-sectional microstructure indicate that the bulky Widmanstatten structure near the fusion line is the main reason for a lower K_{Id}.

Key words: square drill pipe; narrow gap pulsed gas shielded metal arc welding; fracture toughness

Laser tailor welding of aluminum alloy sheet and cup axon formability of TWB LI Yuntao[1,2], ZHANG Wenjun[1], YANG Lijun[3], ZHANG Jian[1,2] (1. School of Materials Science Engineering, Tianjin University of Technology, Tianjin 300384, China; 2. Tianjin Key Laboratory for Photoelectric Materials Devices, Tianjin 300384, China; 3. School of Materials Science Engineering, Tianjin University, Tianjin 300072, China). pp 81 - 84

Abstract: The process and forming performance of laser tailor-welded board (TWB) of 6061 aluminum alloy were studied. The forming characteristics of TWB in the cup axon trials and the influence of welded beam on overall plastic forming of tailor-welded plate were analyzed. The cupping test results of laser TWB shows that the cracking generally appears in the narrow HAZ. The cupping index of TWB was slightly lower than that of base metal. During the numerical simulation process of cupping test with DYNAFORM software, only the location of the welded beam was considered but its type was ignored, and the results showed that the simulation cracking of the TWB easily occurred at the welded seam below the cupping head with the influence of the welded seam, and the simulation results were slightly different from the practical tests, which was possibly related to the set of the welded seam.

Key words: 6061 aluminum alloy sheet; laser tailor-welded; cup axon formability; DYNAFORM simulation

Establishment of cold cracking susceptibility criterion for X80 pipeline steel LI Yajuan[1,2], JIA Peng[1], LI Wushen[2], XIE Qi[2] (1. College of Science, Civil Aviation University of China, Tianjin 300300, China; 2. School of Materials Science and Engineering, Tianjin University, Tianjin 300072, China). pp 85 - 88

Abstract: The influence of welding heat input, preheat temperature and the deposited metal diffusible hydrogen content were considered, the HAZ critical stress of X80 pipeline steel was tested by implant test based on the orthogonal regression design. The significant factors on the critical stress were obtained by analysis of variance. By multiple linear regression, the critical stress equation and the cold cracking susceptibility criterion were established. The critical stress equation was analyzed. It was concluded that the initial diffusing hydrogen content had great influence on cold cracking susceptibility of X80 pipeline steel. When the initial diffusing hydrogen content is lower, the microstructure is found to be the most important factor on the critical stress. When the initial diffusing hydrogen content is higher, the residual hydrogen content has great influence on the critical stress as well as the microstructure.

Key words: pipeline steel; critical stress; cold cracking; range analysis

Study of microstructure and properties in weld metal of TP304 steel under three processes LI Haitao, YANG Wenjie, WANG Jun, YIN Ke (School of Materials Science and Engineering, Jiamusi University, Jiamusi 154007, China). pp 89 - 92

Abstract: Using three different welding processes, the appropriate welding process parameters were selected and three groups welded joints of TP304 stainless steel were prepared successfully. The microstructure and properties in weld metal zone of TP304 stainless steel under different welding methods were studied by X-fluorescent chemical composition analysis, microstructure observations and micro-hardness test. The results show that alloy composition of weld metal are different and distribute uniformly with different welding methods, microstructure morphology and grain size of the solder layer are quite different. Hardness of the joint is not evenly distribute, weld metal is higher than HAZ, and HAZ is higher than the base metal. Hardness of the weld under TIG-MAG process is maximum and TIG-SMAW process is minimum by comparing three methods. TIG-MAG welding method is better for the thin stainless steel.

Key words: TP304 steel; welding procedure; weld metal; X-ray fluorescence; micro hardness

Numerical analysis on crack tip opening displacement of strength mismatched welded joint XIONG Linyu, ZHANG Yanhua (School of Mechanical Engineering and Automation, Beihang University, Beijing 100191, China). pp 93 - 96

Abstract: Elastic-plastic behaviors of strength mismatched welded joints with cracks were investigated with finite element method. Effects of strength mismatching, crack length and stress-strain curve form of base metal on crack tip opening displacement were analyzed. The results show that the crack driving force increases with the increasing of strength mismatch