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结构形式对多芯片子系统激光密封质量的影响

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摘 要：利用激光焊接的优点，采用 ANSYS 软件对多芯片子系统 Al-50Si 壳体与盖板（4047 铝合金）激光密封的结构进行分析，并进行了实物验证. 结果表明，结构形式是影响多芯片子系统激光密封质量的关键因素，方形结构激光焊缝应力比异形结构高出 36% 以上（根据 ANSYS 分析结果），实物验证的方形结构激光焊缝气密性比异形结构低一个数量级. 其原因是激光焊接后，方形结构的焊缝因焊接应力产生了焊接裂纹，影响了焊缝的气密性. 采用 Al-50% Si 复合材料制作的多芯片子系统壳体与 4047 铝合金盖板异形接头形式，可以有效地降低激光焊缝的应力，从而避免焊接裂纹的产生. 结果表明，异形结构的焊缝氦泄漏率可以达到 8.9×10^{-9} Pa·m^3/s，满足了多芯片子系统壳体气密封装要求.

关键词：多芯片；铝硅合金；激光焊接；泄漏率

中图分类号：TG 406 **文献标识码**：A **文章编号**：0253-360X(2014)05-0079-04

0 序 言

随着人们对电子设备小型化、轻量化、多功能、高性能的不断追求[1-3]，多芯片子系统（是指采用多芯片封装技术，将模拟电路、数字电路以及微波功率电路等封装为具有系统级或子系统级模块和组件）得到了广泛应用. 针对多芯片子系统所具有的特点，要求其封装壳体具有高导热、低密度、低热胀系数、可自动化密封性、后续应用工艺的简便性以及可返修性等特性，而只有 Al-50% Si 复合材料最符合要求.

采用 Al-50% Si 制作的多芯片子系统壳体可以钎焊或熔焊进行密封，对于密封性要求较高的多芯片子系统，钎焊焊缝的气密性无法满足，只能熔焊密封. 激光焊接具有能量集中、热影响区小、可以自动焊接异形焊缝等优点，逐渐成为实现铝合金结构连接最具有技术和经济优势的方法[4,5]. 国内外诸多学者针对铝合金激光焊接组织与性能开展了大量研究[6-8]，而针对 Al-50% Si 封装材料的研究并不多见.

文中针对 Al-50% Si 材料制作的多芯片子系统壳体与 4047 铝合金盖板，进行激光焊接，并对焊件进行检漏，研究激光焊接接头形式对激光焊缝气密性的影响，以满足多芯片子系统壳体气密封装要求.

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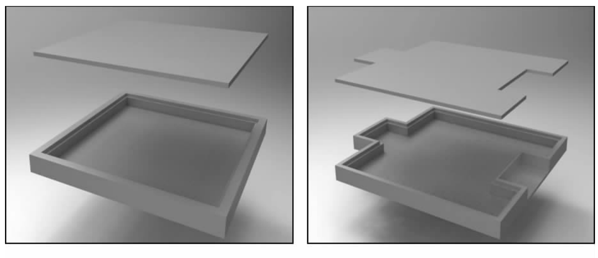
1 试验方法

采用 ANSYS 分析方形与异形焊接接头的焊后应力，其分析模型为：Al-50% Si 制作的多芯片子系统壳体，盖板采用 4047 铝合金，成分见表 1，厚度为 1 mm，激光焊接接头采用嵌入式对接接头，壳体四边台阶高度为 1 mm、宽度为 1 mm，采用方形与异形两种结构（图 1），方形结构外形尺寸为 60 mm × 60 mm × 10 mm，异形结构凸起 10 mm，对称分布.

表 1 4047 铝合金成分（质量分数，%）
Table 1 Compositions of 4047 aluminium alloy

Si	Cu	Mg	Zn	Mn	Fe	Cr	Ti	Al
11～13	≤0.3	≤0.1	≤0.2	≤0.15	≤0.8	≤0.05	≤0.05	余量



(a) 方形 (b) 异形

图 1 方形和异形结构
Fig. 1 Square and special-shaped joint

对方形与异形两种接头形式的样品激光焊接，

进行实物验证,对焊接接头进行气密性检测,并做金相分析.

ANSYS 分析时选择 solid87 单元类型. 其网格划分见图2,各层材料参数见表2. 建模时采用实体,外壳尺寸相对于其它层均较大,即认为外壳底面被固定. 所采用的加载方式为温度载荷,且设为稳态.

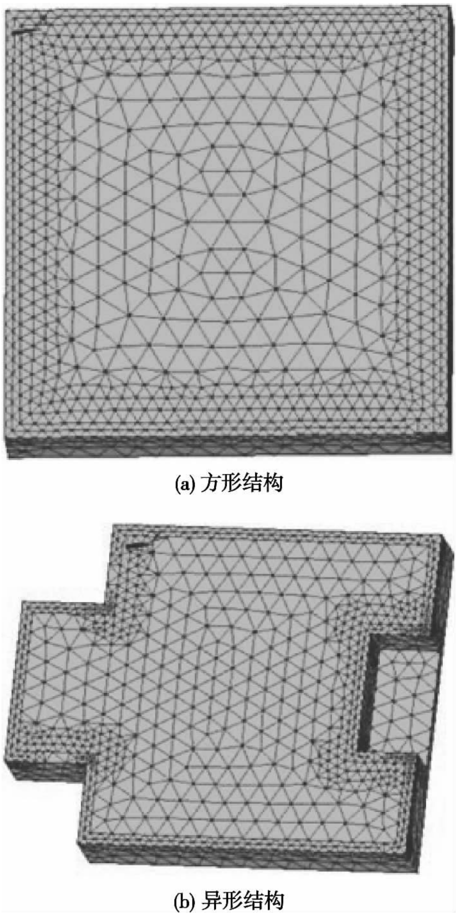


图2 三维网格划分

Fig. 2 3D mesh Figures for weld joint

表2 材料参数表

Table 2 The material parameters of weld joint

样品编号	密度 ρ/ (10^3 kg•m^{-3})	热导率 λ/ (W•m^{-1}K^{-1})	线膨胀系数 α_l/ (10^{-6} m•k^{-1})	杨氏模量 E/GPa	泊松比 ν
4047	2.66	210	21.6	70	0.33
Al-50% Si	2.50	149	11.0	121	0.25

试验时将 Al-50% Si 制作的多芯片子系统壳体机械加工、去污、清洗、干燥后,进行激光环缝焊接试验,焊接示意图如图3所示,采用统一适合的焊接工艺参数(根据 Al-Si 复合材料的成分和工艺特点调整激光功率为 200 W、焊接速度 250 mm/min,负偏焦 0.5 mm),经抛光和用 10% NaOH 溶液腐蚀 20 ~ 40 s,用金相显微镜观察复合材料母材和焊缝的微观组织,分析焊缝的微观组织和缺陷,采用检漏仪测试焊缝的气密性. 综合评价多芯片子系统壳体结构形式对激光焊接焊缝气密性的影响.

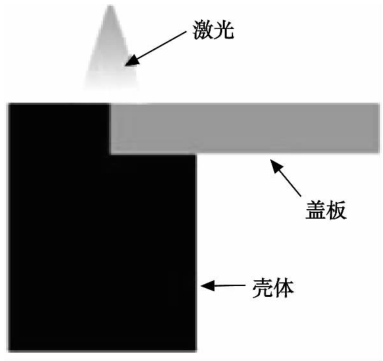


图3 激光焊接示意图

Fig. 3 Schematic of laser welding process

2 试验结果与分析

2.1 结构形式对多芯片子系统激光密封焊缝应力的影响

从 ANSYS 分析的应力云图(图4)可以清晰看

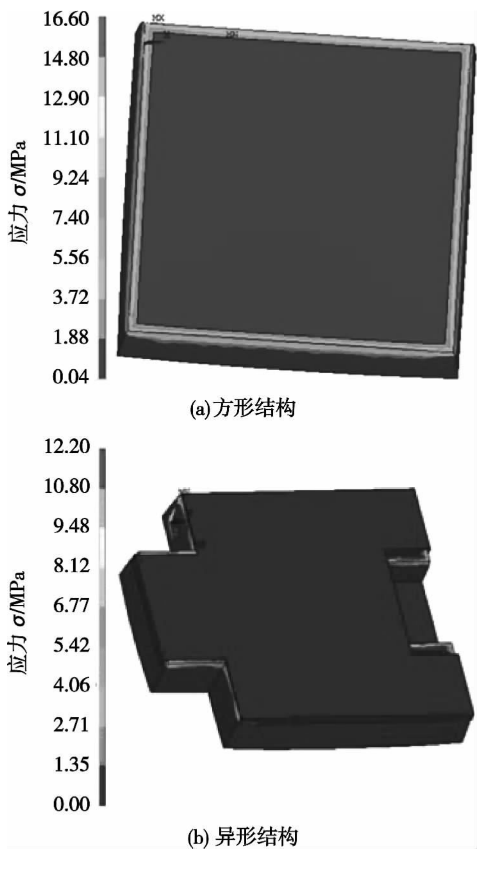


图4 方形与异形焊接接头焊后的应力分布

Fig. 4 Stress pattern of square and special-shaped joint

出,方形结构整个焊缝的应力为 5.56 ~ 16.6 MPa,最大应力为 16.6 MPa,位于方形结构的四个角; 异形结构整个焊缝的应力为 0 ~ 12.2 MPa,最大应力为 12.2 MPa,最大应力点位于凸起的拐角处,比方形结构减小了 36%.

无论从整个焊缝的应力分布,还是从最大应力角度比较,异形结构接头应力比方形结构小很多.

2.2　结构形式对多芯片子系统气密性的影响

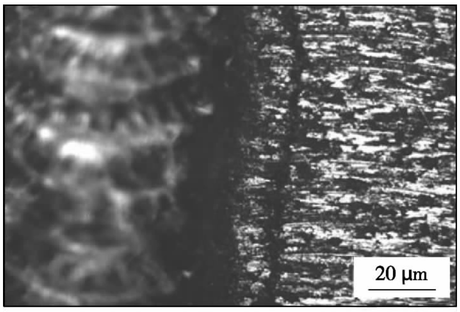
方形与异形结构的实物验证结果见表 3. 可以看出,应力较小的异形结构的焊接接头,焊缝质量较好,焊缝气密性达到 10^{-9} 量级; 而对于应力较大的方形结构的焊接接头,焊缝气密性较低.

表 3　激光焊接的焊缝质量检验结果

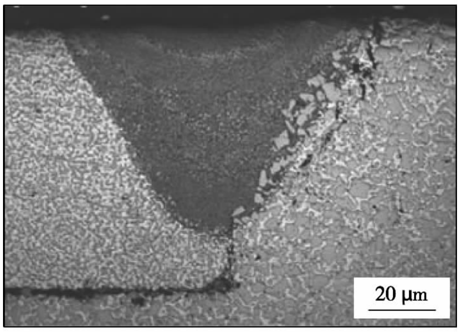
Table 3　Leakage rate of laser welding joint

样品编号	壳体焊接接头形式	氦泄漏率 $Q/(Pa\cdot m^3 s^{-1})$	焊缝外观质量
1	方形	6.4×10^{-6}	热影响区裂纹
2	异形	2.9×10^{-8}	无
3	方形	2.7×10^{-6}	热影响区裂纹
4	异形	8.9×10^{-9}	无
5	方形	6.5×10^{-4}	纵向裂纹
6	异形	1.6×10^{-8}	无

金相显微镜观察发现应力较大的方形结构的焊接接头的焊缝热影响区裂纹见图 5. 这是方形结构的焊接接头焊缝气密性较低的主要原因.



(a) 焊缝外观



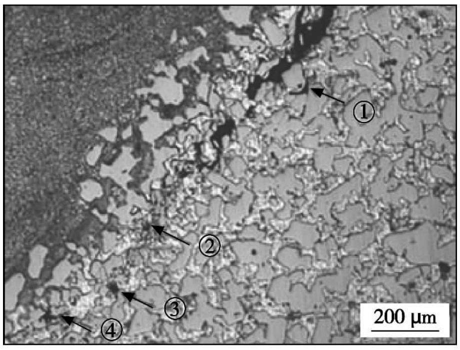
(b) 焊缝剖面

图 5　方形焊接接头焊缝的热影响区裂纹

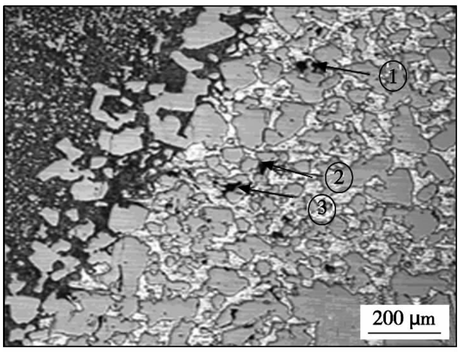
Fig. 5　Heat affected zone crack of square joint

2.3　方形结构激光焊接裂纹的产生原因分析

多芯片子系统 AlSi 壳体采用激光密封焊接时,由于是局部高温加热,在焊接熔化区温度很高,远远超过了铝的熔点和 Al-Si 共晶温度点,过高的焊接熔池温度使硅相之间相互扩散、吞并而偏聚长大,而硅颗粒越大,则容易在颗粒附近富集气孔[3]. 激光焊接过程中,硅相之间相互扩散、吞并而偏聚长大更加严重. 颗粒附近富集气孔在焊后应力作用下极易成为裂纹源,导致焊接裂纹的产生. 由于方形结构焊后焊缝中的应力较大,更容易引起焊接裂纹(参见图 6a 中①,②,③,④);而异形结构接头焊后的应力较低,焊缝中硅周围的气孔没有形成裂纹参见图 6b 的①,②,③. 因此,方形结构焊后焊缝中的应力是焊缝裂纹产生的根本原因,采用异形结构,可以有效地降低焊后应力,避免焊接裂纹的产生. 另外,加工缺陷也会引起激光焊接裂纹.



(a)方形结构



(b)异形结构

图 6　焊接接头焊缝的热影响区硅颗粒附近富集气孔

Fig. 6　Porosity around Si particle in heat affected zone of joint

试验中激光焊接接头采用嵌入式的对接接头,对焊件的加工精度有较高的要求,图 7 为盖板加工缺损,导致焊缝空洞,成为裂纹源,在焊接应力的作用下,产生裂纹的情况,这种现象影响了焊缝的密封性能.

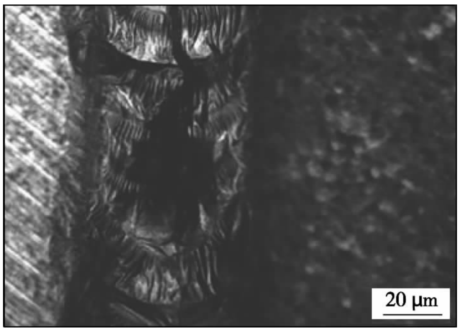


图7 加工盖板缺口引起激光焊接接头裂纹
Fig. 7 Crack caused by Machining defects

3 结 论

（1）结构形式是影响多芯片子系统激光密封质量的重要因素，激光焊接后，方形结构焊缝的应力远大于异形结构，即焊缝密封性低.

（2）方形结构焊后焊缝中的应力是焊缝裂纹产生的根本原因，采用异形结构，可以有效地降低焊后应力，避免焊接裂纹的产生.

（3）采用 ANSYS 对焊接接头结构的焊后应力分析结果，与实物试验结果吻合性较好.

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sing this technique, experiments were conducted in 4 mm thick sheets of aluminum alloy 5A02 in H14 condition. The results show that the bonding widths of cross-FSSW joints had been increased, the adverse effects of interface distortion and the lack of material of the keyhole had been avoided. cross-FSSW joints were found to be superior to traditional Friction stir spot welds produced under optimum conditions in lap-shear.

Key words: cross-friction stir spot welding; friction stir welding; aluminum alloy; mechanical properties

The theory and application of the virtual fatigue test of welded structures based on the master S – N curve method

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Abstract: The necessity and feasibility of the virtual fatigue test technology of welded structure were discussed firstly. Then a basic theory of a new method called the master S – N curve method, which can be used for assessment of fatigue life of welded structure and published by the ASME (2007) standard, has been discussed as well. Following this discussion, a conclusion has been given that is the new method is resulted from the welded structure fatigue failure mechanism instead of fatigue failure test data. So this method is more suitable as the core algorithm in welding virtual fatigue test then nominal stress method. Finally, two applications have been given, and the results show that during the design phase, the welded structure virtual fatigue test technology based on the master S – N curve method, can effectively identify stress concentrations happed at each weld in a complex welding structure. In fact, this just is needed in design process.

Key words: welded structure; fatigue damage; virtual fatigue test; the master S – N curve; stress concentration

Laser welding technology of multi-chip subsustem shell and cover

YU Shenglin[1,2], XUE Songbai[1], YAN Wei[3], JI xuan[2], ZHU Xiaojun[3] (1. College of Materials Science and Technology, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China; 2. Nanjing University of Information Science and Technology, Nanjing 210044, China; 3. Nanjing Research Institute of Electronics Technology, Nanjing 210039, China). pp 79 – 82

Abstract: Adopted the advantages of laser welding and by use of ANSYS software, the structure of the Al-50Si shell and the cover (4047 aluminum alloy) of the multi-chip subsystems which sealed by laser welding was analyzed, and the physical verification was also carried out. It was proved that structure form is the key factor which affected the quality of multi-chip subsystems which sealed by laser welding, the stress in laser weld of square structure is 36% higher than that in special-shaped structure (according to ANSYS analysis results), and the air tightness of the square structure is lower by almost one order of magnitude than that of special-shaped structure, which performed by physical verification. The reason is that after laser welding, the welding cracks induced by welding stress in the weld of square structure, so as to affect the air tightness of the weld. By adopt of special-shaped structure of multi-chip subsystems made from Al-50Si composite materials and the cover made from 4047 aluminum alloy, the stress in the welds can be effectively reduced, so the cracks in the weld are actually avoidable during laser welding. The result was indicated that the helium leak rate of the weld of special-shaped structure can reach to 8.9×10^{-9} Pa·m^3/s, which met the hermetic package requirement of multi-chip subsystems.

Key words: multi-chip; Al-Si alloys; laser welding; leakage rate

Virtual weld experiment system of billet flash butt welding process

LU Ning (School of Mechanical-Electronic and Automobile Engineering, Beijing University of Civil Engineering and Architecture, Beijing 100044, China). pp 83 – 87

Abstract: In view of the characteristics of flash welding system for large section rolling steel billet, mechanical kinematic models of welding equipments were built by using dynamics simulation software ADAMS. In which forging hydraulic servo system nonlinear model of the flash butt welding process was proposed in AMESim. Moreover, the servo control system for virtual welding system was built by utilizing the Simulink package of MATLAB software. By analysis of the data transmission characteristics between simulation softwares, a shared channel for dynamic data carrier was established by MATLAB software. A digital platform of welding electromechanical system was brought into forward, by which virtual experiment on electromechanical system of billet flash welding process can be carried out.

Key words: billet; flash butt weld; virtual experiment

Analysis of principle of least action on explosive welding process

SHI Changgen, ZHAO Linsheng, HOU Hongbao, WANG Yu (PLA University of Science Technology, Nanjing 210007, China). pp 88 – 90

Abstract: The principle of least action, basic law of the nature and the final rule of the physics, was found to be followed by the explosive welding process by theoretical analysis and interface test. Namely the optimal welding interface can be obtained with the least explosive charge. The bonding energy of the interface can be looked upon the action on the course. To minimize the bonding energy, these rules must be followed such as the lower limit of explosive charge, the upper limit of span and the explosive of the lower critical explosion velocity. The principle of least action is achieved on the explosive welding process, and the bonding interface will be best.

Key words: explosive welding; bonding interface; upper limit; lower limit

Investigation of thermal shock resistance of the nanostructured zirconia thermal barrier coatings treated by laser glazing

WANG Hongying, LI Zhijun, TANG Weijie, HAO Yunfei (Shenzhen Polytechnic, Shenzhen 518055, China). pp 91 – 94

Abstract: The nanostructured zirconia coatings were pre-