化学镀表面改性石英纤维复合材料与因瓦合金的真空钎焊

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摘 要: 采用化学镀镍方法对石英纤维复合材料进行了表面改性, 研究了镀镍工艺对改善石英纤维复合材料焊接性的作用. 结果表明, 采用 Ag-Cu共晶箔片对化学镀镍改性的石英纤维复合材料与因瓦合金在 830 ℃保温 10 min进行真空钎焊后, 形成由 (Cu, Ni), Ni(s, s), Ag(s, s)等固溶组织及 Ni元素与石英纤维间钉扎作用共同构成的界面连接结构, 此时接头室温抗剪强度达到 29 MPa, 这也说明, 镀镍层通过扩散反应发挥了增强复合材料表面结构、实现致密冶金连接的作用.

关键词: 石英纤维复合材料; 因瓦合金; 化学镀镍; 钎焊
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0 序 言

以纤维织物作为增强体的先进复合材料, 由于具有高比强、耐高温、耐腐蚀和疲劳、阻尼减震性好、破损安全性好等优点, 成为航空航天及国防军备领域技术发展的标志[1,2]. 作为一种陶瓷基透波材料, 以石英纤维束为编织体、硅溶胶为填充物的石英纤维复合材料 (quartz fiber reinforced silica composites, QFSC) 以其独特的耐热、轻质及电气性能等优点逐渐在航空航天领域得到研究和应用[3-5].

纤维复合材料在实际应用过程中, 大多需要与金属连接在一起, 从而充分发挥其与金属的综合性能. 除了胶粘工艺以外, 目前关于纤维复合材料与金属的连接主要涉及真空钎焊研究, 如 C/C复合材料、C/SiC复合材料的真空钎焊等[6-8]; 而对 QFSC的研究, 则主要集中在材料的制备和性能上.

作者通过试验发现, QFSC质地疏松、力学性能各向异性 (平行于纤维编织方向的强度较低, 约 8~11 MPa) 是造成其与异种材料连接性能较差的主要因素. 为解决上述问题, 文中试验采用化学镀镍工艺对 QFSC进行表面改性, 然后选用 Ag-Cu共晶箔进行该材料与因瓦合金的真空钎焊, 获得了较高抗剪强度的接头, 同时分析了化学镀镍方法改善 QFSC焊接性的机理.

1 试验方法

试验用 QFSC是 2.5维编织的石英纤维布层叠后浸入硅溶胶, 经一定温度烧结而成, 其试块加工尺寸为 5 mm×5 mm×5 mm, 形貌如图 1a, b所示, 其沿纤维编织方向的抗剪强度为 11 MPa. 真空钎焊前, 通过化学镀镍工艺对 QFSC试块进行表面致密化处理, 在 QFSC表面紧密包覆一层厚度约 10 μm的金属镍层 (图 1c), 从而有效地增强了 QFSC表面力学性能, 使其平行于纤维编织方向的抗剪强度可以达到 17 MPa. 试验用因瓦合金 (4J36) 被加工成 5 mm×3 mm×200 mm试片. 装配前, 采用 1000号金相砂纸对上述两种试件的焊接表面进行研磨, 并在丙酮中用超声波清洗干净.

试验采用厚度为 100 μm的 Ag-Cu共晶箔片作为钎料, 在 Centorr3520真空加热炉中进行钎焊试验, 钎焊工艺曲线如图 2a所示, 钎焊试验温度分别为 800, 830及 840 ℃, 保温时间均为 10 min. 试件按镀镍 QFSC/Ag-Cu/因瓦合金的三明治结构装配.

采用 Instron-5569电子万能材料试验机对焊接接头抗剪性能进行测定, 性能测定模型如图 2b所示. 通过 OLYMPUS-SZX12光学显微镜及 HITACHI S-3400N扫描电子显微镜 (SEM) 观察接头界面, 并进行能谱分析 (EDS), 判定了接头的界面组成.

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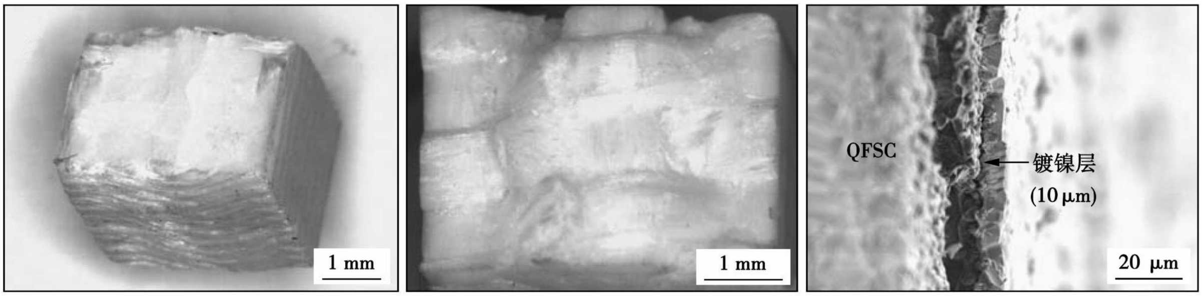
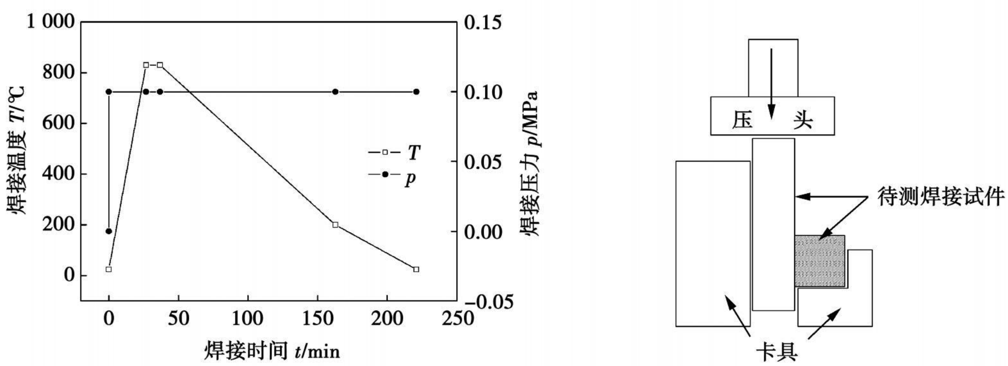


(a) QFSC的编织形貌 (b) 纤维构造 (c) 镀镍QFSC截面SEM图(镀镍层厚约10 μm)

图 1 QFSC的形貌特征

Fig. 1 Morphology of quartz fiber reinforced SiO_2 composites (QFSC)



(a) 镀镍QFSC与因瓦合金真空钎焊工艺曲线 (b) 接头抗剪性能测试模型

图 2 镀镍 QFSC与因瓦合金真空钎焊的工艺设计示意图

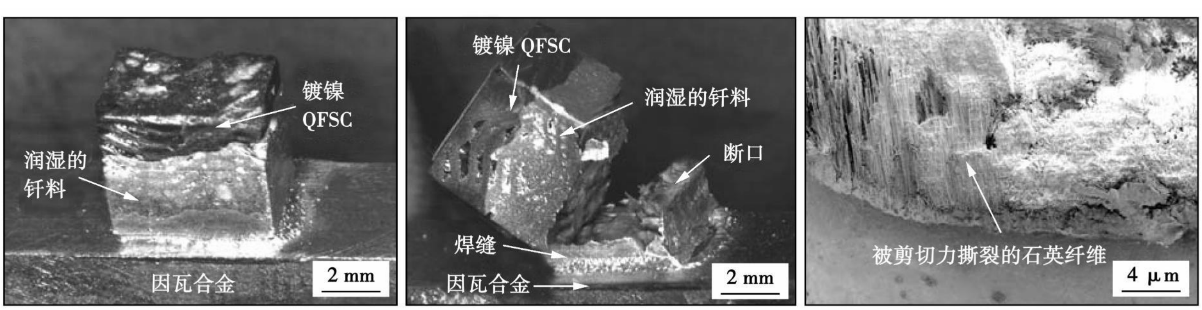
Fig. 2 Schematic of vacuum brazing QFSC to Invar

2 试验结果及分析

2.1 接头性能及分析

钎焊后得到如图 3a所示的连接件，对其进行静载抗剪性能测定，加载速度为 1 mm/min，各焊接工艺参数焊接后所得接头力学性能如表 1所示，其中焊接装配方式为镀镍 QFSC/AgCu钎料/因瓦合金.

从表 1数据可以看出，在 830 ℃真空加热 10 min钎焊，镀镍 QFSC与因瓦合金可获得 29 MPa(室温抗剪强度)的高强度连接，其连接强度远高于 QFSC的固有强度(焊接方向强度为 11 MPa)，也高于镀镍石英复合材料在该方向的强度(17 MPa)，说明镀镍层的增强包覆和钎料熔合对提高接头强度起到



(a) 试件钎焊连接件 (b) 接头抗剪性能测试断裂件 (c) QFSC的断口形貌

图 3 焊接试件形貌及断口特征(830 ℃, 10 min)

Fig. 3 Macro image of brazed specimens and fractures(830 ℃, 10 min)

较好作用.

表 1　镀镍 QFSC与因瓦合金的钎焊接头室温抗剪性能

Table 1　Shear strengths of joints brazed at different parameters

焊接工艺参数		接头室温抗剪强度 $R_τ$/MPa	
温度 T/℃	时间 t/min	测定值	平均值
800	10	22.9, 22.3, 19.8	21.6
830	10	34.9, 26.4, 27.1	29.5
840	10	23.0, 19.4, 20.1	20.8

图 3b所示为接头的剪切断裂形貌,断口位于距焊缝约 1~2 mm的 QFSC基体上.观察焊接试件的外观可以发现,焊接过程中 Ag-Cu共晶钎料对镀镍 QFSC及因瓦合金进行了较充分润湿及铺展.因瓦合金侧,钎料已与母材融为一体,在合金表面铺展成紧密的熔合层;镀镍 QFSC侧,钎料也已得到充分润湿及铺展,对镀镍 QFSC外表面进行了致密包覆.从距焊缝由近及远的方向看,QFSC表层由"镀镍层+润湿的钎料"过渡为单一的"镀镍层".在接头承受剪切力作用时,断裂在 QFSC侧发生,由于剪切断口处的 QFSC由镀镍层及 Ag-Cu钎料熔敷层双层包覆,受力后镀层内部纤维束断裂并引发连接件开裂(图 3c),故而接头抗剪强度值大于镀镍 QFSC固有强度.

图 4所示为镀镍 QFSC/Ag-Cu钎料/因瓦合金钎焊接头界面照片.由图 4可见,接头结构致密,界面处没有发现微孔、残渣等焊接缺陷.QFSC与因瓦合金通过镀镍层及钎料熔敷层实现了紧密连接.QFSC的焊接表面纤维束间隙被浸入的金属镍填充.为进一步研究界面结构,对界面各区域进行 EDS分析,结果如表 2所示.

表 2　镀镍 QFSC/Ag-Cu/因瓦合金钎焊接头界面各区域元素组成(原子分数,%)

Table 2　Elements distribution at different regions of QFSC plated/Ag-Cu/Invar joint

位置	O	Si	Ag	Fe	Ni	Cu	可能相
1	5.64	0.93	0.00	61.87	31.57	0.00	(Fe,Ni)
2	5.64	0.90	0.73	7.89	40.73	44.11	(Cu,Ni)
3	14.31	1.88	65.18	4.28	6.18	8.16	Ag(s,s)
4	4.06	1.49	1.69	2.22	20.78	69.76	(Cu,Ni)
5	6.21	0.00	0.87	1.50	87.17	4.25	Ni(s,s)
6	11.63	6.11	0.27	1.82	77.28	2.89	SiO_2,Ni(s,s)

由 EDS分析结果可知,钎焊过程中,钎料中的 Cu原子向两侧的母材扩散,与 Ni相熔合(图 4中的 2,4浅灰色相),形成(Cu,Ni)固溶体.特别是在 QFSC侧,镀镍层中的 Ni原子受热溶解和扩散充分,在向石英纤维束间隙浸渗填充的同时,也与钎料中的 Cu原子相互固溶(图 4中的 5,6深灰色相).正是金属镀层及钎料的浸渗、固溶实现了焊接接头的紧密连接,形成了由(Cu,Ni),(Ag,Cu),Ag(s,s)和 Cu(s,s)为主的界面结构:Invar/(Cu,Ni)+Cu(s,s)/(Ag,Cu)+Ag(s,s)/Cu(s,s)+(Cu,Ni)/Ni(s,s)+QFSC.

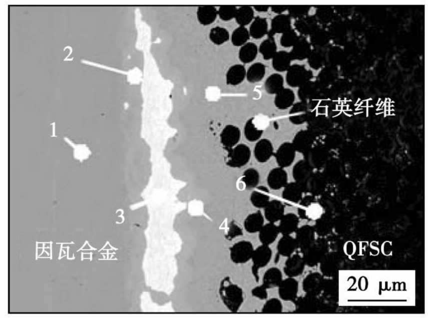


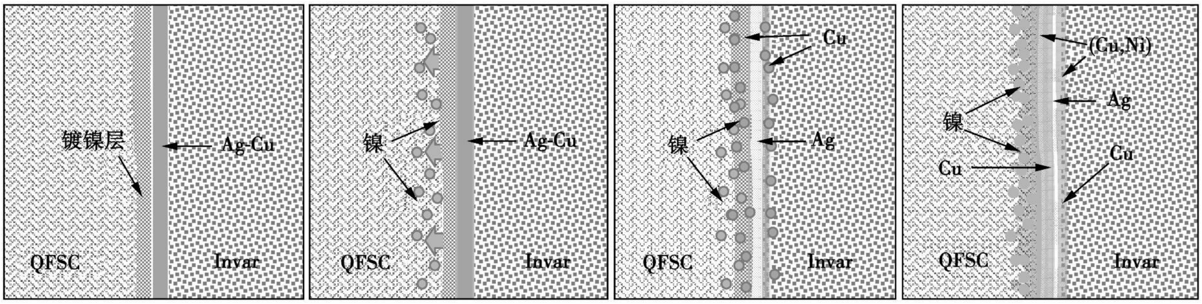
图 4　镀镍 QFSC/Ag-Cu/因瓦合金接头 SEM图(830 ℃,10 min)

Fig.4　SEM of QFSC plated/Ag-Cu/Invar joint brazed at 830 ℃ for 10 min

2.2　接头形成模型

在钎焊加热过程中,镀镍层与 QFSC,Ag-Cu钎料发生了相互交织行为(图 5).在钎焊前,QFSC表面包覆着物理沉积的镀镍层,在固定压力的作用下镀镍 QFSC与钎料及 Invar合金达到物理接触.加热升温阶段,随温度升高,Ni原子的热扩散能力增强(根据 Arrhenius公式,温度升高,原子的扩散系数增大),逐渐向石英纤维束间隙浸渗;当温度升至 354 ℃时,镍与钎料中的铜开始固溶;在钎焊加热保温阶段,镍与 Ag-Cu共晶液相组织互溶,使镀镍层及因瓦合金均与液态钎料形成扩散熔合;在随后的冷却降温过程中,液态钎料与镀镍层、合金表面形成的互溶组织逐渐凝固,形成固溶连接,渗入到 QFSC间隙的镍起到钉扎作用,对纤维束紧紧包覆、增强,最终实现致密的钎焊接头.

通过对 QFSC的焊接性及接头形成过程的分析,可以得出制约质地疏松的编织结构复合材料焊接性的关键问题之一就是减小表面纤维的易碎脆断的发生.对表面焊接部位进行局部增强改性,既能有效改善纤维编织表面对连接性能的不利影响,又可保证复合材料基体的特有性能不受影响,从而实现纤维复合材料的实用性焊接.



(a) 钎焊前 (b) 加热升温阶段 (c) 钎焊保温加热阶段 (d) 降温阶段

图 5 镀镍 QFSC 钎焊界面形成模型(Ag-Cu 共晶钎料)
Fig. 5 Brazing interface forming model of QFSC plated/Invar using Ag-Cu eutectic

3 结 论

采用表面镀镍的方法对质地疏松 QFSC 进行表面致密化及金属化改性,进而提高了复合材料的焊接适应性. 选用 Ag-Cu 共晶箔对镀镍 QFSC 及因瓦合金进行真空钎焊,在 830 ℃保温 10 min 钎焊后,可获得抗剪强度为 29 MPa 的焊接接头,此接头承受剪切力后断裂于 QFSC 基体上. 镀镍层在 QFSC 与异种材料的焊接中发挥了增强和连接的双重作用. 金属镀层的应用,有效地解决了材质疏松类编织复合材料在连接方面存在的表面质脆易断及改善焊接性的问题,从而实现较高强度的连接.

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MAIN TOPICS, ABSTRACTS & KEY WORDS

Measurements and analysis of onward force on stir-pin in FSW process WANG Xijing, ZHANG Zhongke, HAN Daobin, ZHANG Changqing (State Key Laboratory of Gansu Advanced Non-ferrous Metal Materials, Lanzhou University of Technology, Lanzhou 730050, China). p 1—4

Abstract: The effects of welding parameters on the forward force of the stir-pin were investigated with the mechanical signal detecting system during friction stir welding LF2 and LY12 aluminum alloys. The results show that the onward force will increase with welding speed and heel plunge depth increasing during welding the same materials, but when the various phenomena occur, the onward force increases at first, reaches the stabilization, and then decreases with rotational speed increasing, the higher the materials hardness, the larger the onward force is. The onward force of the stir-pin is connected with the heat generation and the deforming volume of advancing side metal during welding, when the deforming volume increases and the temperature decreases, the onward force will increase.

Key words: aluminum alloy; friction stir welding; onward force; data acquisition

Simulation of coupling of electromagnetic and thermal fields for process of high-frequency induction heating of HFW pipe YU Enlin[1], HAN Yi[1], FAN Yulin[1], ZHAO Yuqian[2] (1. College of Mechanical Engineering, Yanshan University, Qinhuangdao 066004, China; 2. Northeastern University at Qinhuangdao, Qinhuangdao 066004, China). p 5—8

Abstract: The effects of temperature distribution on welding quality in high-frequency induction heating (HFIH) were investigated in order to improve the weld quality in HFW (high-frequency weld) pipe. According to the characteristics of induction heating, the secondary development on the ANSYS finite element software was carried out. Based on physics environment method and APDL language, the program of coupling of electromagnetic and thermal fields for process of high-frequency induction heating of HFW pipe and a 3-D FEM model were built up, and the temperature distribution rule of the coupling of electromagnetic and temperature fields was given. The simulation results for the production of steel pipe ϕ 219 mm show that the distribution of the array of small core is better, which meet the production well.

Key words: high-frequency weld; induction heating; coupling of electromagnetic and thermal; finite element simulation; core

Vacuum brazing of nickel-plated quartz fiber reinforced SiO_2 composites and Invar ZHAO Lei[1], ZHANG Lixia[1], TIAN Xiaoyu[1], HE Peng[1], FENG Jicai[1] (1. State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China; 2. National Key Laboratory of Precision Hot Processing of Metals, Harbin Institute of Technology, Harbin 150001, China). p 9—12

Abstract: Electroless nickel plating technology was carried out for the surface modification of quartz fiber reinforced SiO_2 composites, and the vacuum brazing of nickel-plated composites with Invar alloy was also investigated, which was brazed by using Ag-Cu eutectic foils at 830 ℃ for 10 min. The results show that nickel plating improves the surface structure of quartz fiber reinforced SiO_2 composites, and the maximum shear strength of joint is 29 MPa.

Key words: quartz fiber reinforced SiO_2 composites; Invar; electroless plating; brazing

Investigation of low-frequency magnetic field radiation on inverter welding power source ZHANG Jun, WANG Shiying, SONG Yonglun (College of Mechanical Engineering & Applied Electronics Technology, Beijing University of Technology, Beijing 100124, China). p 13—16

Abstract: The mechanisms of two kinds of magnetic field mainly distributed around power source and cables are analyzed, and their accuracy is verified through measurements. It's found that several modulation effects on current from rectifier to inverter module in the power source result in stacking effect of magnetic field among power-frequency magnetic field and magnetic fields generated by the rectifier and inverter module. Furthermore, the magnetic field frequency around the cables strongly depends on the frequency of IGBT, low-frequency and time-varying magnetic field strength increases as the current ripple increase, but varies inversely as distance approximately. Extra electromagnetic radiation to operator results from closing to and bending the cables, therefore, it's great significant to further understand and descript the electromagnetic radiation under welding environment to standardize the welding criteria and also to reduce magnetic filed radiation exposure as far as possible.

Key words: inverter welding power source; low-frequency magnetic field; measurement; magnetic filed radiation exposure

Microstructure and properties of arc sprayed tin-based babbitt coating ZHANG Zhongli[1], DUAN Sihua[1], ZHANG Hongbin[1], LI Deyuan[1], SUN Wenzhe[2], YANG Chunqi[3] (1. School of Material Science and Engineering, Shenyang University of Technology, Shenyang 110870, China; 2. Shenyang Blower Works Group Co., Ltd, Shenyang 110142, China; 3. Shenyang Yuanda Compressor Manufacturing, Shenyang 110027, China). p 17—20, 24