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Al_2O_3-TiC/Q235 真空扩散钎焊界面组织及抗剪强度

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摘 要：为了获得 Al_2O_3-TiC 陶瓷基复合材料与 Q235 钢的接头，采用 Ti/Cu/Ti 复合中间层对 Al_2O_3-TiC 复合材料与 Q235 低碳钢进行了真空扩散钎焊。通过扫描电镜、能谱分析和电子探针、抗剪试验等测试方法对 Al_2O_3-TiC/Q235 扩散钎焊界面的组织、成分及结合强度进行分析。结果表明，控制加热温度为 1 110 ℃，可获得界面抗剪强度 122 MPa 的 Al_2O_3-TiC/Q235 扩散钎焊接头，Ti/Cu/Ti 复合中间层与 Al_2O_3-TiC 和 Q235 润湿性较好，并发生一定程度的扩散反应，在 Al_2O_3-TiC 与 Q235 之间形成厚度约80 μm 的界面过渡区，过渡区内形成的组织结构主要是 Ti_3AlC_2，Fe_2Ti，Cu 和 TiC。

关键词：Al_2O_3-TiC；扩散钎焊；抗剪强度；组织特征
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0 序 言

随着陶瓷材料制备技术的改进和性能的不断提高，陶瓷日益成为高温结构件和耐磨零部件的优选材料，广泛应用于刀具、密封圈、火花塞、模具以及大量高温发热体的制备。但是单相陶瓷较低的断裂韧性及力学性能的不稳定性限制了其在工程领域的大规模推广应用。因此，研究者正致力于在单相陶瓷中添加一种或几种化合物形成复合陶瓷，以改善单相陶瓷的力学性能，如在 Al_2O_3 中添加 SiC，Ti(C，N)等形成一系列 Al_2O_3 陶瓷基复合材料(CMC)，其耐磨性和强韧性明显优于单相 Al_2O_3 陶瓷[1－3]。其中 Al_2O_3-TiC 陶瓷基复合材料具有硬度高、化学稳定性好、强韧性较高的特点，有望在耐高温、抗冲击、耐磨损等场合得到广泛应用[4－6]。

为了利用金属的韧性缓解 Al_2O_3-TiC 陶瓷基复合材料的脆性，有必要将 Al_2O_3-TiC 陶瓷基复合材料与金属进行连接。目前陶瓷与金属常用的连接方法有钎焊和扩散焊方法[7－9]。采用扩散焊方法时，为了降低接头的应力集中，通常在陶瓷与金属之间添加活性金属作为中间层进行焊接。焊接过程中，中间层金属发生熔化，在一定的保温时间作用下与两侧母材发生扩散反应，形成扩散焊接头[10，11]。文中采用 Ti/Cu/Ti 复合中间层对 Al_2O_3-TiC 陶瓷基复合材料与 Q235 低碳钢进行扩散钎焊，测定扩散钎焊接头的抗剪强度，采用扫描电镜和电子探针分析了 Al_2O_3-TiC/Q235 扩散钎焊接头的组织结构。研究结果为获得高强度的 Al_2O_3-TiC/Q235 接头、进一步促进 Al_2O_3-TiC 陶瓷基复合材料的应用提供了试验依据。

1 试验方法

试验材料采用 ϕ55 mm × 4 mm 的热压烧结 Al_2O_3-TiC 陶瓷基复合材料和 ϕ55 mm × 3 mm 的 Q235 低碳钢圆片，复合中间层采用钛粉＋铜箔＋钛粉，总厚度为50 μm。Al_2O_3-TiC 陶瓷基复合材料的成分(质量分数，%)分别为 Al_2O_3 43.8，TiC 40.6，Mo 8.9，Ni 2.4，Cr 3.8，V 0.5。Al_2O_3-TiC 陶瓷基复合材料的组织特征见图 1。

扩散钎焊前，将试验母材表面用丙酮浸泡，然后用酒精清洗干净。扩散钎焊工艺参数为加热温度 1 060～1 150 ℃，保温时间 45～60 min，焊接压力 12 MPa，真空度 10^{-4} Pa。

扩散钎焊后垂直于界面切取试样，采用 CMT 5105 型电子万能试验机对 Al_2O_3-TiC/Q235 接头进行剪切，剪切速度为 0.15 mm/min；采用能谱分析剪切

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界面成分;采用 JXA-840 扫描电镜和 JXA-8800R 电子探针对接头的组织结构和成分进行观察和分析;采用 D/MAX-RC 型 X 射线衍射仪对接头形成的物相进行判定。

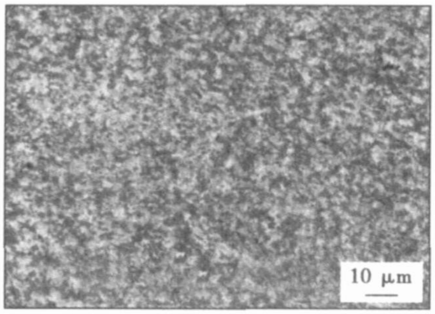


图 1 Al_2O_3-TiC 陶瓷基复合材料的组织特征

Fig. 1 Microstructure of Al_2O_3-TiC ceramics matrix composite

2 试验结果及分析

2.1 抗剪强度

图2 示出不同扩散钎焊加热温度下得到的 Al_2O_3-TiC/Q235 接头的抗剪强度。可见,随着加热温度从 1 060 ℃升高至 1 110 ℃,接头抗剪强度从 91 MPa 增加到 122 MPa。这主要是由于中间层中的 Ti 元素和 Cu 元素在扩散钎焊过程中向两侧母材发生了充分的扩散,降低了接头的应力集中。但当温度超过1 110 ℃再继续增加时,由于高温下接头组织的粗化,反而使 Al_2O_3-TiC/Q235 扩散钎焊接头抗剪强度下降。因此,控制扩散钎焊加热温度在 1 110 ℃左右,可以获得具有较高抗剪强度的 Al_2O_3-TiC/Q235 扩散钎焊接头。

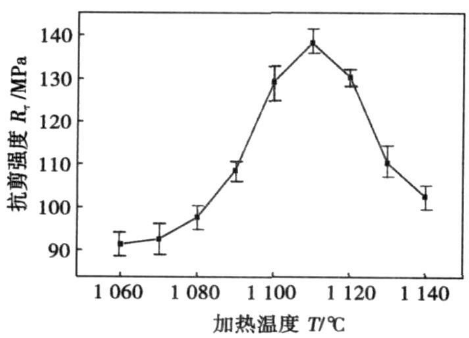
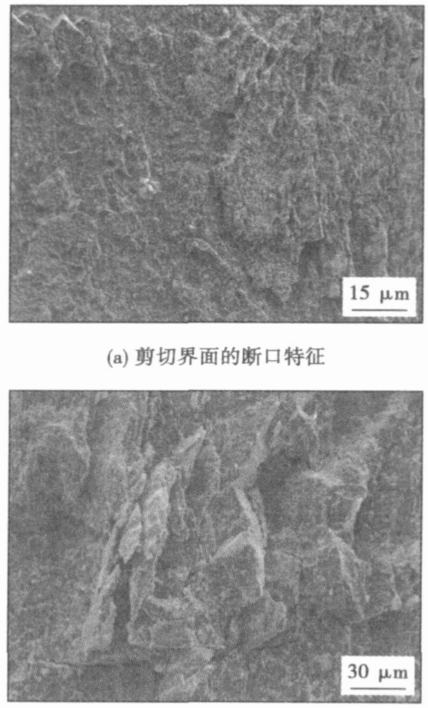


图 2 不同扩散钎焊温度的 Al_2O_3-TiC/Q235 接头抗剪强度

Fig. 2 Shear strength of Al_2O_3-TiC/Q235 joint with different heating temperature

图 3a 示出的 Al_2O_3-TiC/Q235 剪切界面断口形貌,呈现出明显的脆性断裂特征。采用能谱(EDS)对剪切界面(图 3b)进行分析表明,断裂面的主要成分是 Al, Ti 和 O 元素。因此,Al_2O_3-TiC/Q235 接头的剪切断裂是发生在界面靠近 Al_2O_3-TiC 一侧。这是由于采用 Ti/Cu/Ti 作为中间层,不仅可以改善 Al_2O_3-TiC 与 Q235 之间的润湿性,还能够缓解接头应力。所以,受 Al_2O_3-TiC 母材脆性的影响,接头靠近 Al_2O_3-TiC 一侧脆性较大,容易发生断裂。



(a) 剪切界面的断口特征

(b) 界面脆性断裂

图 3 Al_2O_3-TiC/Q235 剪切界面的断口特征

Fig. 3 Fracture characterization at Al_2O_3-TiC/Q235 shearing interface

2.2 接头组织特征

Al_2O_3-TiC/Q235 扩散钎焊接头的组织特征见图 4。Ti/Cu/Ti 复合中间层全部熔化,部分中间层与两侧母材通过润湿和发生扩散反应而实现结合,复合中间层与母材之间界面结合致密,没有不连续和显微空洞产生。Al_2O_3-TiC 与 Q235 之间形成了一个明显的界面过渡区,厚度约为80 μm。由于复合中间层与两侧母材之间的扩散反应,使界面过渡区的组织晶粒明显小于 Q235 钢母材。

Al_2O_3-TiC 与 Q235 之间界面过渡区的组织特征见图 5a。界面过渡区有 4 个组织结构不同的区域,由 I, II, III, IV 示出。I 区代表母材 Al_2O_3-TiC, II 区是靠近 Al_2O_3-TiC 一侧组织较为细小的区域, III 区是界面过渡区中心组织较为粗大的区域,并且弥散分布有白色颗粒状组织, IV 区是Q235 钢母材组织。界

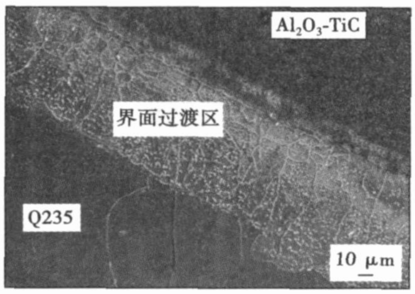


图 4　Al_2O_3-TiC/Q235 扩散钎焊接头的组织特征

Fig. 4　Microstructure of Al_2O_3-TiC/Q235 diffusion brazing joint

面过渡区组织晶粒边界上也聚集有大量的白色颗粒。采用电子探针对界面过渡区典型组织的化学成分进行了测定，结果见图 5b，c，d。

界面过渡区靠近 Al_2O_3-TiC 一侧的 Ⅱ 区域内组织主要含(原子分数，%)Ti44-C29-Al22(图 5b)，其中 Al 和 C 元素主要是从 Al_2O_3-TiC 向界面扩散而来，而 Ti 元素一部分来自 Al_2O_3-TiC，还有一部分来自 Ti 元素中间层，因此区域 Ⅱ 的 Ti 元素含量达 44%，这些元素有可能在靠近 Al_2O_3-TiC 一侧形成 Ti-Al-C 化合物；界面过渡区中心区域 Ⅲ 基体成分(原子分数，%)分别为 Fe51-Ti36-Cu13(见图 5c)；基体上弥散分布的白色颗粒成分(原子分数，%)为 Ti48-C43 和少量的 Fe，这些化合物主要形成 TiC 增强粒子(见图 5d)。

2.3　XRD 分析

采用 X 射线衍射对界面靠近 Al_2O_3-TiC 和 Q235 侧的剪切断面进行了分析，试验用 CuK_α 靶，工作电压为 60 kV，工作电流为 45 mA。XRD 试验结果如图 6 所示。

经与粉末衍射卡片对比，由于 Al_2O_3-TiC 母材中的 Al 和 C 元素向 Al_2O_3-TiC/Q235 界面的扩散，在界面靠近 Al_2O_3-TiC 一侧生成了 Ti_3AlC_2 和 TiC。Ti_3AlC_2 是一种三元层状可加工陶瓷材料，既具有金属良好的高温塑性，又具有陶瓷高模量、高熔点、高稳定性和良好的抗氧化性能等。因此，新形成的 Ti_3AlC_2 有利于保证 Al_2O_3-TiC/Q235 接头的强韧性。

在界面 Q235 一侧，主要形成了 Fe_2Ti 和 TiC，这主要是由中间层的 Ti 元素与 Q235 扩散的 Fe 和 C 元素相互反应的产物。此外，在界面过渡区还分布有少量的 Cu 元素，这表明中间层 Cu 元素熔化后向两侧发生了扩散但并未发生化学反应生成新的结构。由于衍射分析是对 Al_2O_3-TiC/Q235 接头的剪切断面，位置是界面靠近 Al_2O_3-TiC 一侧，受 X 射线探测深度的影响，界面过渡区没有出现 Ti-Cu 化合物的衍射峰。

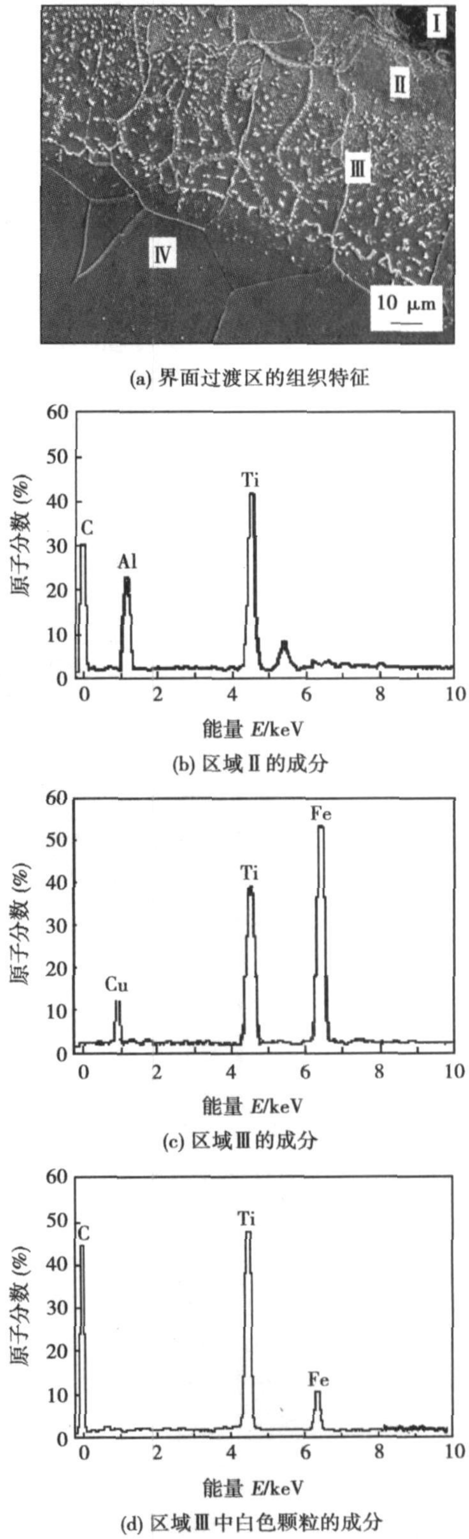


图 5　Al_2O_3-TiC/Q235 界面过渡区的组织特征及成分

Fig. 5　Microstructure and composition of Al_2O_3-TiC/Q235 interfacial transition zone

X 射线衍射结果表明，在 Al_2O_3-TiC/Q235 扩散钎焊接头主要存在 Ti_3AlC_2，Fe_2Ti，Cu 和 TiC 结构，与电子探针的成分分布相结合，可见，从 Al_2O_3-TiC 一侧经过界面过渡区到 Q235，其组织结构分别为 TiC

$+Al_2O_3$，Ti_3AlC_2+TiC，$Cu+Fe_2Ti$，TiC 和 Fe。

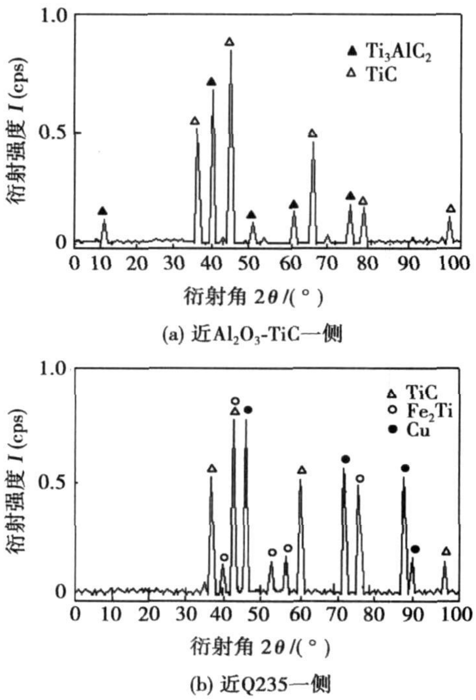


图6 Al_2O_3-TiC/Q235界面的XRD衍射图

Fig. 6 X-ray diffraction pattern at Al_2O_3-TiC/Q235 interface

3 结 论

(1) 采用Ti/Cu/Ti作为复合中间层，控制加热温度为1 110 ℃，可以成功实现Al_2O_3-TiC陶瓷基复合材料与Q235碳钢的扩散钎焊，获得抗剪强度为122 MPa的Al_2O_3-TiC/Q235接头。接头的剪切断口形貌呈现明显的脆性破断，剪切断裂位置大都发生在接头靠近Al_2O_3-TiC一侧。

(2) 扩散钎焊过程中Ti/Cu/Ti复合中间层全部熔化，部分中间层与两侧母材发生扩散反应，形成明显的界面过渡区。界面过渡区厚度约为80 μm，通过电子探针结合X射线衍射分析，界面过渡区的组织结构主要有Ti_3AlC_2，Fe_2Ti，Cu和TiC相。

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versity, Tianjin 300072, China). p17—19, 24

Abstract: Arc spraying and plasma cladding process was used to prepare the aluminum composite coating. The microstructure and phase structures of the clad alloy layer and the interface of alloy layer and steel matrix composites were analyzed. The results show that the tight alloy layer without pore and inclusion is obtained, and the coating and the steel are metallurgically compacted. The clad alloy layer consists of phase Fe_3Al, FeAl, α-Fe and Al_2O_3. Microhardness of the clad alloying layer will be 514 HV.

Key words: plasma cladding; Fe_3Al; intermetallic compound

Application of pre-scanning technology with laser to seam-curved tracking XIAO Zengwen, LIU Jifeng, CHEN Zhichao, GONG Xun (Department of Mechanical Engineering, Nanjing Institute of Technology, Nanjing 211167, China). p20—24

Abstract: The structured-light technology of traditional seam tracking makes front guiding error great if the curvature is varying. To solve the problem, a structured-light pre-scanning technology with double lines is produced. The seam is scanned before welding along the planned track of the robot. A laser line is added under the welding torch tip to indicate the front guiding error that will be recorded on time sequence and be eliminated when welding. A seam tracking system and its mathematical model are established. An image processing system is advanced, which the integrations of image processing technologies including median filtering, threshold transforming, thinness transforming and subsection beeline fitting locate the seam middle exactly. Tests show that the technology combined with the image processing system has the characteristics of strong anti-jamming, little error and fast processing speed, and it can meet the request of real time tracking.

Key words: seam tracking; structured-light; pre-scanning; image process; curved seam

Microstructure and shear strength of diffusion brazed Al_2O_3-TiC/Q235 joint WANG Juan[1], LI Yajiang[1], S. A. GERASIMOV[2] (1. Key Laboratory of Liquid Structure and Heredity of Materials, Shandong University, Jinan 250061, China; 2. Materials Science Department, Bauman Moscow State Technical University, Moscow 105005, Russia). p25—28

Abstract: An Al_2O_3-TiC/Q235 joint, Al_2O_3-TiC ceramic composite with steel Q235, was obtained by diffusion brazing in vacuum, using a combination of Ti and Cu as multi-interlayer. The interfacial strength was measured by shear testing and the result was explained by the fracture morphology. Microstructure of the Al_2O_3-TiC/Q235 joint was investigated by scanning electron microscope (SEM), energy-dispersion spectroscopy (EDS) and X-ray diffraction (XRD). The results indicate that the Al_2O_3-TiC/Q235 joint with a shear strength of 122 MPa can be obtained by controlling heating temperature at 1 110 ℃, multi-interlayer Ti/Cu/Ti is fused fully and diffused reaction to produce an obvious interfacial transition zone with a thickness of about 80 μm, and there are Ti_3AlC_2, Fe_2Ti, Cu and TiC in the transition zone.

Key words: Al_2O_3-TiC; diffusion brazing; shear strength; microstructure

Cross-section modeling of weld bead for rapid prototyping by MAG welding based on wavelet transform CAO Yong, ZHU Sheng, SUN Lei, SHEN Canduo, LIANG Yuanyuan, WANG Wanglong (National Defense Key Laboratory for Remanufacturing, Academy of Armored Forces Engineering, Beijing 100072, China). p29—32

Abstract: A new modeling method of weld bead profile by MAG welding process was proposed and the edge of the profile was extracted based on wavelet transform. The different interpolation methods, the cubic spline, the constrained cubic spline and the B-spline curve, were utilized respectively, the cross-section edge of weld bead was fitted by least square method, and then the mathematical model of the profile was achieved. The experimental results show that the method is effective to detect the cross-section outline of the profile, the constrained cubic interpolation is preferred choice to interpolate the data of the profile, and the cross-section profile mathematical model of weld bead is sine curve under our experiments.

Key words: rapid prototyping; wavelet transform; edge detection; modeling

Microstructure and wear resistance of plasma cladding Al_2O_3+TiO_2/Fe alloy composite coating LU Jinbin, LIANG Cun, PENG Zhuqin, ZHANG Zhaojun (College of Material and Chemical Engineering, Zhongyuan University of Technology, Zhengzhou 450007, China). p33—36

Abstract: Plasma cladding Ni-Cr-B-Si-Fe-based alloy coating and Fe-based alloy composite coating with Al_2O_3+TiO_2 were obtained on the Q235 substrate, and microstructure, microhardness and wear resistance of the two coatings were investigated contrastively. The results show that the interface solidification form of Fe-based alloy composite coating with Al_2O_3+TiO_2 have changed. They become small dendrite from primary lathy dendrite, and offer core for solidification. The microstructure is mainly based on γ-Fe with fine particles, and its microhardness can reach 600~655 HV0.2.

Key words: plasma cladding; microhardness; wear resistance; Al_2O_3+TiO_2

Data collecting system of pipe arc acoustic emission characteristics LIU Lijun[1,2], LAN Hu[1], DUAN Hongwei, WEN Jianli[1] (1. School of Material Science & Engineering, Harbin University of Science and Technology, Harbin 150080, China; 2. Ningbo Institute of Technology, Zhejiang University, Ningbo 315100, China). p37—40

Abstract: As the arc sound signal contains plenty of welding information which is an important source signal for welding quality control, arc acoustic emission signal (AAES) propagated in pipeline structure is low-noise, and AAES collecting system is designed for pipe TIG welding. The hardware system consists of sensor, signal adaptor circuit, data collecting card and industrial workstation. Based on virtual instrument programming software (LabVIEW), the high speed AAES collecting software system is designed by means of triggering interrupt, packaging function modules and calling dynamic