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TC4/TC17 线性摩擦焊接头组织及力学性能

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摘　要： 针对航空发动机整体叶盘常用的TC4和TC17钛合金开展线性摩擦焊研究，对接头的组织进行了金相和电镜观察，并测量了焊接过程的温度. 结果表明，接头分为母材、热力影响区和焊合区三部分，其热力影响区组织只发生了α相和β相沿受力方向的重新排列，焊合区发生了再结晶. 温度测量表明，焊接过程的最高温度可达到1 270 ℃，超过了钛合金的β转变温度. 拉伸测试表明，在室温和200 ℃进行拉伸测试时，接头的抗拉强度与TC4母材等强，而在400 ℃进行测试时，接头抗拉强度能达到TC4母材的95%.

关键词： 线性摩擦焊；钛合金；组织；温度
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0　序　　言

整体叶盘各部位的受力情况各不相同，叶片主要承受气动载荷和高频振动应力，要求高的强度、塑性和高周疲劳性能，一般应采用等轴组织；轮盘主要承受离心负荷，要求高的抗蠕变能力、低周疲劳性能和断裂韧性，一般应采用网篮组织. 若采用单一组织(均质)钛合金整体叶盘，势必造成某些部位的性能不富裕，甚至不足，难以满足高性能发动机对不同部位性能各有侧重又彼此兼顾的设计要求. 因此迫切需要研制各部位具有不同的组织和性能的整体叶盘，即双性能整体叶盘，以充分发挥材料及结构潜力，减轻结构重量.

文中针对整体叶盘常用TC4(叶片材料)和TC17(轮盘材料)钛合金开展异种材料钛合金线性摩擦焊研究，分析线性摩擦焊接头组织特征并对焊接过程的温度进行测试.

1　试验方法

试验所用材料为TC4和TC17钛合金，其主要化学成分见表1和表2[1]. 试样尺寸为130 mm×100 mm×20 mm，焊接面积为2 000 mm^2.

在北京航空制造工程研究所自制的线性摩擦焊设备上进行试验，焊前用丙酮擦拭待焊界面，焊后利用线切割截取金相试样和电镜试样，对金相试样研磨抛光并用氢氟酸、硝酸的水溶液腐蚀后，在DM6000M金相显微镜上进行金相观察. 在JEOL扫描电镜上进行观察，透射电镜制样并在JEM2010透射电镜上进行组织观察，利用YOKOGAWA DX2000测温装置对接头进行温度测试，测试位置如图1所示. 对接头进行焊后消除应力退火后再进行拉伸性能的测试.

表1　TC4钛合金的化学成分(质量分数，%)
Table 1　Chemical compositions of TC4 titanium

Al	V	Ti
5.8~7.0	2.8~3.8	余量

表2　TC17钛合金的化学成分(质量分数，%)
Table 2　Chemical compositions of TC4 titanium

Al	Sn	Zr	Mo	Cr	Ti
4.5~5.5	1.6~2.4	1.6~2.4	3.5~4.5	3.5~4.5	余量

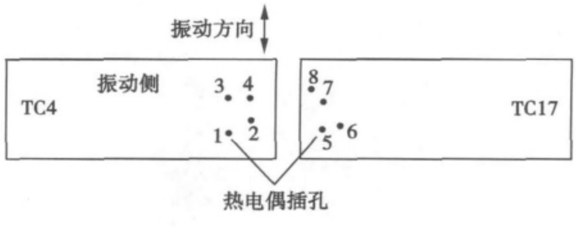

图1　各通道热电偶位置图
Fig. 1　Thermocouple position

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2 接头组织分析

2.1 宏观组织分析

结果表明,线性摩擦焊接头由母材(BM)、焊合区(W)和热力影响区(TMAZ)组成,但并未发现明显的热影响区(HAZ). 这主要是由于钛合金的热导率较小. 在线性摩擦焊条件下,变形对TC4和TC17钛合金的影响范围远大于温度,因此在接头中只观察到了TMAZ,而并未发现明显的HAZ. 图2为接头宏观组织形貌. 从图2中可以看出TC4/TC17钛合金线性摩擦焊焊缝形状边缘宽、中间细,经初步分析认为是焊接过程焊缝不同位置的温度分布不同及焊接过程材料的流动导致的.

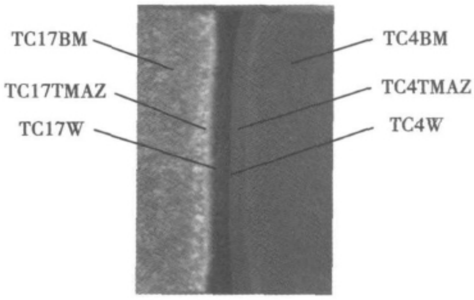


图2 接头宏观组织形貌
Fig. 2 Macrostructure of joints

2.2 显微组织分析

2.2.1 母材组织

图3为TC4母材组织. 从图3中可以看出,TC4母材组织由β转变组织及等轴α相组成,等轴状α相所占比例约为60%. 而图4中TC17母材组织形貌中可以看出,TC17钛合金母材为网篮组织,是因为β-Ti晶胞共有6个滑移面和2个滑移方向,能为α相生长提供12个取向,α相片层按照上述12种取向关系形核并长大,大量的可能取向导致层片束取向多次重复,结果形成了一种非常有特色的显微组织—网篮组织[2].

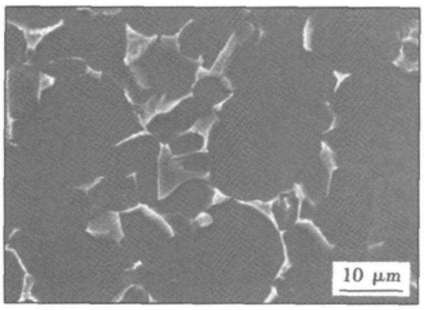


图3 TC4母材组织
Fig. 3 Microstructure of TC4 base metal

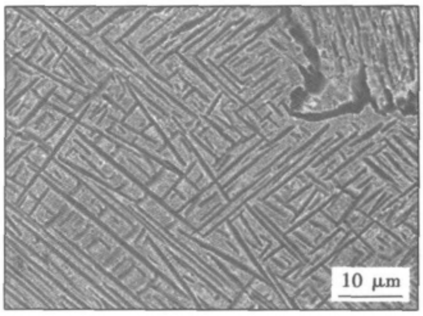


图4 TC17母材组织
Fig. 4 Microstructure of TC17 base metal

2.2.2 热力影响区(TMAZ)组织

对于TC4钛合金来说,热力影响区由高度变形的α相和β相晶粒组成,见图5,与母材组织相似,但是母材等轴α相在该区沿着受力方向被拉长. TC17热力影响区中组织也沿着受力方向重新排列,且针状的α组织有球化变粗的趋势,见图6. 这表明对于TC4和TC17钛合金其热力影响区的温度并未

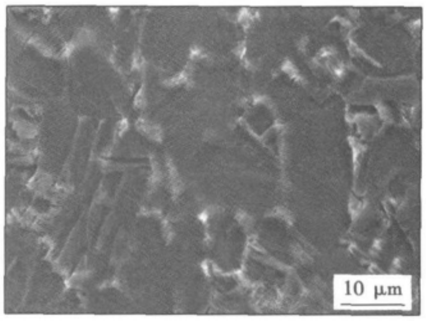


图5 TC4侧热力影响区组织
Fig. 5 Microstructure of TC4 TMAZ

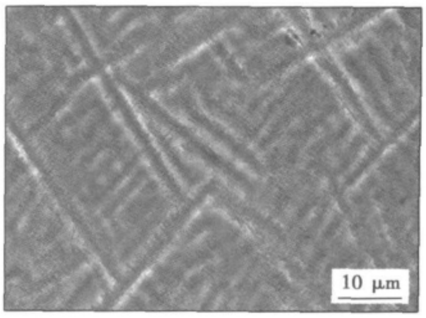
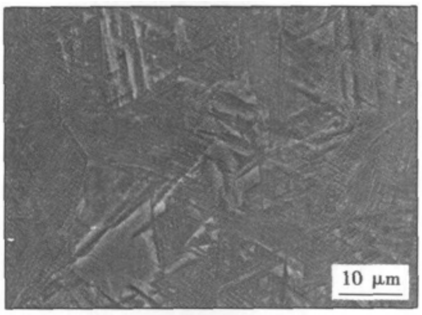


图6 TC17热力影响区组织
Fig. 6 Microstructure of TC17 TMAZ

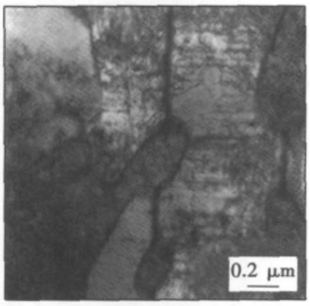
超过 β 转变温度，而只发生了 α 相和 β 相晶粒沿受力方向重新排列[3,4].

2.2.3　焊合区(W)组织

图 7 为 TC4 侧焊合区组织形貌. 从图 7a 可以看出，与母材相比，TC4 侧焊合区的组织有很大不同，母材是等轴 $\alpha+\beta$ 转变组织，而焊合区则发生了再结晶，晶粒内部为细小的片层 $\alpha+\beta$ 组织，这是因为线性摩擦焊过程中，摩擦界面上的材料是在高温、高应变速率下变形，使原始 β 晶粒发生动态再结晶，再结晶晶粒的尺寸限制了 $\alpha+\beta$ 片层结构的尺寸，发生该组织的转变也说明线性摩擦焊过程中界面的温度超过了 β 转变温度. 图 7b 中 TC4 侧焊合区透射电镜形貌表明，焊合区发生了再结晶，而且晶粒内部存在大量位错. TC17 侧焊合区也发生了动态再结晶见图 8a，晶粒内部为细小的片层组织见图 8b，焊合区组织形态与母材组织的差别也说明该区的温度超过了 TC17 钛合金 β 转变温度.

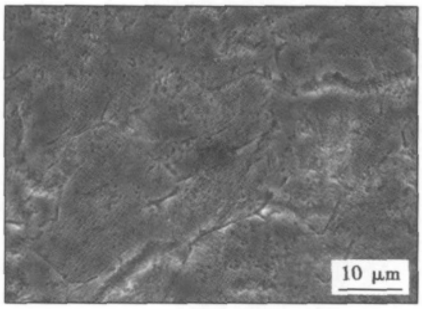


(a) TC4侧焊合区扫描电镜形貌

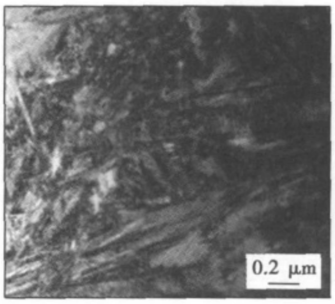


(b) TC4侧焊合区透射电镜形貌

图 7　TC4 侧焊合区组织形貌
Fig. 7　Microstructure of TC4 weld



(a) TC17侧焊合区扫描电镜形貌



(b) TC17侧焊合区透射电镜形貌

图 8　TC17 侧焊合区组织形貌
Fig. 8　Microstructure of TC17 weld

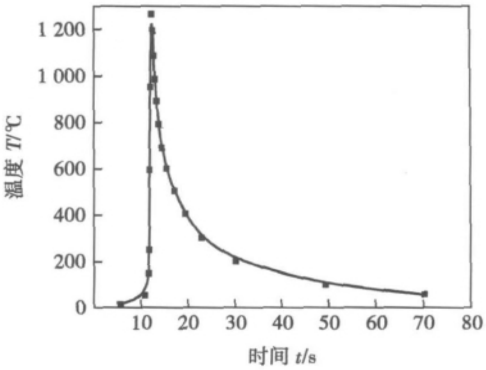


图 9　测温曲线
Fig. 9　Temperature variation curve

从图 9 的测量结果可以看出，线性摩擦焊过程最高温度可以达到 1 270 ℃ 左右，超过了 TC4 和 TC17 钛合金相变温度，这也与组织观察结果相符合，焊合区发生了再结晶，而且组织形态不同于原始母材.

3　接头温度测试分析

按照图 1 将热电偶埋入试件中，焊接过程中由于摩擦及顶锻作用，塑化金属以飞边形式被挤出，部分热电偶相继发生脱落，因此脱落的热电偶没有测得降温曲线，图 9 是试验测得的典型温度变化曲线.

4　接头力学性能测试及分析

对 TC4，TC17 母材以及 TC4/TC17 线性摩擦焊接头进行了室温、200，400 ℃ 的拉伸性能测试，测试结果见表 3，所有接头拉伸均断于 TC4 母材一侧见图 10. 由测试结果可知，试验所测得的接头强度实

际为 TC4 母材的强度,说明接头的抗拉强度不低于同状态的 TC4 母材.

表3 接头及母材的拉伸性能

Table 3 Mechanical properties of joints and base metal

试验温度 T/℃	材料	抗拉强度 R_m/MPa	屈服强度 R_{eL}/MPa	断后伸长率 A(%)	断面收缩率 Z(%)
室温	TC4	915	870.83	18.08	45.17
	接头	936.67	894.17	11.42	41.42
	TC17	1140	1 080	7.33	11.17
200	TC4	706.7	610	22.5	60.92
	接头	722.5	625.83	16.17	57.33
	TC17	1013	870	10.92	23.5
400	TC4	581.67	470	22.83	64.75
	接头	552.5	458.33	17.58	64.58
	TC17	937	769	11.33	23.92

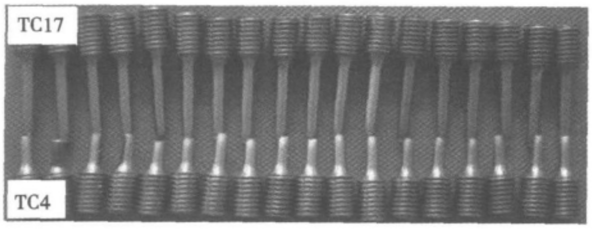


图10 TC4/TC17 接头拉伸性能测试结果

Fig. 10 Tensile testing pieces of joints

5 结 论

(1) 对于 TC4/TC17 线性摩擦焊接头,其宏观组织明显分为三个区: 母材区、热力影响区和焊合区,其热力影响区组织与母材类似,只发生了 α 相和 β 相沿着受力方向重新排列,而焊合区组织与母材不同,发生动态再结晶.

(2) 焊接过程温度测量结果表明,焊接过程最高焊接温度可达到 1 270 ℃,超过了钛合金的相变温度.

(3) 接头拉伸性能测试结果表明,接头的性能与 TC4 母材相当.

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creases. On the basis of differences in equivalent cathode/anode drops and the welding arc characters in EN/EP polarity, the welding wire gets more energy as the EN ratio increases, so the wire melting rate is larger than DC MIG welding. At a constant wire feed speed and welding speed, the penetration depth and bead width decrease while the reinforcement becomes high as the EN ratio increases. Accordingly, AC Pulse MIG welding technology can solve the burn through problem in welding thin sheet joints and can greatly improve the gap bridging ability in lap joints. What is more, this technology can also improve the welding speed and welding bead quality for thin sheet joints.

Key words: aluminum alloy welding; AC pulse MIG welding; EN ratio; wire welding rate

Analytical model of wire temperature distribution during hot-wire TIG welding process ZHAO Fuhai[1,2], HUA Xueming[1,2], YE Xin[1,2], WU Yixiong[1,2,3] (1. Welding Engineering Institute of Material Science and Engineering Shanghai Jiaotong University, Shanghai 200240, China; 2. Shanghai Key Laboratory of Materials Laser Processing and Modification, Shanghai Jiaotong University, Shanghai 200240, China; 3. State Key Laboratory of Metal Matrix Composite, Shanghai Jiaotong University, Shanghai 200240, China). pp 97 – 100

Abstract: Based on the law of energy conservation, the mathematical model considering the effect of heat loss on the hot-wire temperature distribution was developed. The accuracy of the mathematical model was validated by comparing the calculating result with the experimental results. The effect of wire diameter, hot-wire current, wire feeding speed, and wire extension on temperature distribution of hot-wire elaborately was discussed. The results show that the mathematical model has so high accuracy that it can be used to analyze the heating process of wire and satisfies the need of controlling the welding quality. The smaller the wire diameter and wire feeding speed are, the higher the temperature of the position on the wire extension having the same distance away from the power-feeding point is. The higher hot-wire current is, the higher the temperature is. However, the larger the wire extension is, the higher the temperature of the position on the wire having the same distance away from the wire-feeding point is.

Key words: hot-wire TIG welding process; heat-loss; temperature distribution of hot-wire; mathematical analytical model

Development of flux for Sn-Zn lead-free solder HAN Ruonan[1], XUE Songbai[1], HU Yuhua[2], WANG Zongyang[1], JA Jianyi[1] (1. College of Materials Science and Technology, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China; 2. The 55th Research Institute, China Electronic Technology Group Corporation, Nanjing 210016, China). pp 101 – 104

Abstract: The speadabitity of Sn-9Zn solder on Cu substrate with four different types of flux was studied by spreading experiment method. The experimental results indicated that Sn-9Zn solder, matching the flux-A4 with stannous sulfonate (20%) as the main activator without halogen which exhibited excellent wettability. The largest spreading area was 65.7 mm^2, increased respeetively by 16.1%, 116.1%, 85.1% compared with the NH_4Cl-$ZnCl_2$, resin and water-solubility fluxes. Besides, the newly developed flux with combination of 20% stannous sulfonate and diethanolamine, succinic acid could remarkably improve the wettabiltiy of Sn-9Zn solder that the largest spreading areas were 76.5 mm^2, 72.5 mm^2 when the contents of diethanolamine, succinic acid were at 8%, 10%.

Key words: Sn-Zn; soldering flux; spreading areas

Effect of aging temperature on microstructure and properties of deposited metal for type 15-5PH precipitation hardened stainless steel QI Yanchang, ZHANG Xiaomu, PENG Yun, TIAN Zhiling (State Key Laboratory of Advanced Steel Processes and Products, Central Iron & Steel Research Institute, Beijing 100081, China). pp 105 – 108

Abstract: Aging temperature is an important aging treatment parameter of deposited metal for type 15-5PH precipitation hardened stainless steel. The welding deposited metal was conducted by gas tungsten arc welding and aging treatment was carry out at different temperature after solution treatment. After aging treatment the microstructure and properties of deposited metal were investigated. The results indicate that microstructure of deposited metal by aging treatment consists predominately of martensite, residual austenite and ε-Cu. The increasing of aging temperature results in the increasing of amount of austenite and the size of ε-Cu, the variation of ε-Cu from increasing to decreasing. The strength of deposited metal drops and toughness improves with the increasing of aging temperature due to the increasing of amount of austenite.

Key words: aging temperature; microstructure; properties; deposited metal

Structure and mechanical properties of TC4/TC17 linear friction welding joint JI Yajuan[1], LIU Yanbing[2], ZHANG Tiancang[1], ZHANG Chuanchen[1] (1. AVIC Beijing Aeronautical Manufacturing Technology Research Institute, Beijing 100024, China; 2. No. 94170 Unit of People's Liberation Army, Xi'an 710061, China). pp 109 – 112

Abstract: TC4 and TC17 titanium usually used on aeroengine blisk were studied. The microstructures were analyzed by metallograph and transmission electron microscope. The temperature during the welding process was also measured. The investigation showed that the joints included three zones, base metal (BM), thermal mechanical affected zone (TMAZ) and welding zone (W). The TMAZ microstructure was similar to base metal, alpha and beta phase were elongated along the stress direction, recrystallization occurred in the weld zone. The induced microstructures were different from the BM. The maximum temperature can reach 1 270 ℃ which exceeds the titanium beta transformation temperature. the tensile test result showed that joint tensile strength was equal to that of the TC4 at room temperature and 200 ℃, while the testing temperature is 400 ℃, the joint tensile strength can reach 95% of the TC4 base mental.

Key words: linear friction welding; titanium; microstructure; temperature