

# 新型高速旋转电弧窄间隙 MAG 焊接

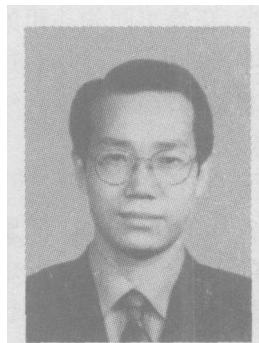
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摘 要: 研究开发了一种新型窄间隙 MAG 焊接系统。在该系统中, 焊丝穿过电机的空心轴后从导电嘴的偏心孔送出, 电机带动导电杆和偏心导电嘴旋转, 从而使焊丝端部的电弧以一定直径高速旋转, 以保证窄间隙焊接接头具有足够的侧壁熔深。焊接试验结果表明, 这种旋转电弧焊接系统能在不同的旋转速度和旋转直径下稳定可靠地工作, 并且明显地改善了窄间隙焊缝侧壁熔透, 避免了接头底部指状熔深的出现, 同时提高了焊接熔敷效率。

关键词: 窄间隙焊; 旋转电弧; 焊缝成形; MAG 焊接

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## 0 序 言

窄间隙 MAG 焊是一种以活性气体保护的大厚板熔化极电弧焊接工艺。通常采用 I 形焊接坡口, 因此焊缝截面小、焊接效率高、接头性能好, 已在造船、压力管道与容器, 以及钢结构制造中获得越来越多的应用<sup>[1, 2]</sup>。

在实际的窄间隙焊接应用中, 如何保证足够的焊缝侧壁熔深, 是人们不得不面对的主要问题之一。为了解决这个问题, 已经提出了几种解决方案, 典型的如旋转电弧、麻花焊丝及蛇形焊丝等焊接新工艺<sup>[1, 3-5]</sup>。其中, 旋转电弧焊接工艺在明显改善焊缝侧壁熔透的同时, 还能提高焊丝熔化速度, 因此是一种更为实用的方法。在传统的旋转电弧焊接机构中<sup>[1, 3]</sup>, 电机驱动一对齿轮, 然后带动导电嘴和电弧旋转。由于使用了齿轮传动, 相应的焊炬结构较为复杂, 体积和传动噪声都比较大, 因此使其实用性受到了影响。

为了使焊炬做得更小、更轻, 研究提出了一种不使用齿轮传动的新型高速旋转电弧焊接系统, 并进行了窄间隙 MAG 焊接试验, 以研究该系统的有效性以及旋转工艺参数对焊缝成形的影响规律。

## 1 新型旋转电弧焊接系统原理

新型高速旋转电弧焊接系统的原理, 如图 1 所

示, 主要由空心轴电机、碳刷、导电杆和偏心导电嘴等构成。送丝机送出的焊丝, 通过电机的空心轴和导电杆后, 从偏心导电嘴送出。碳刷与焊接电缆相接, 同时在压缩弹簧的作用下, 与导电杆上的法兰台

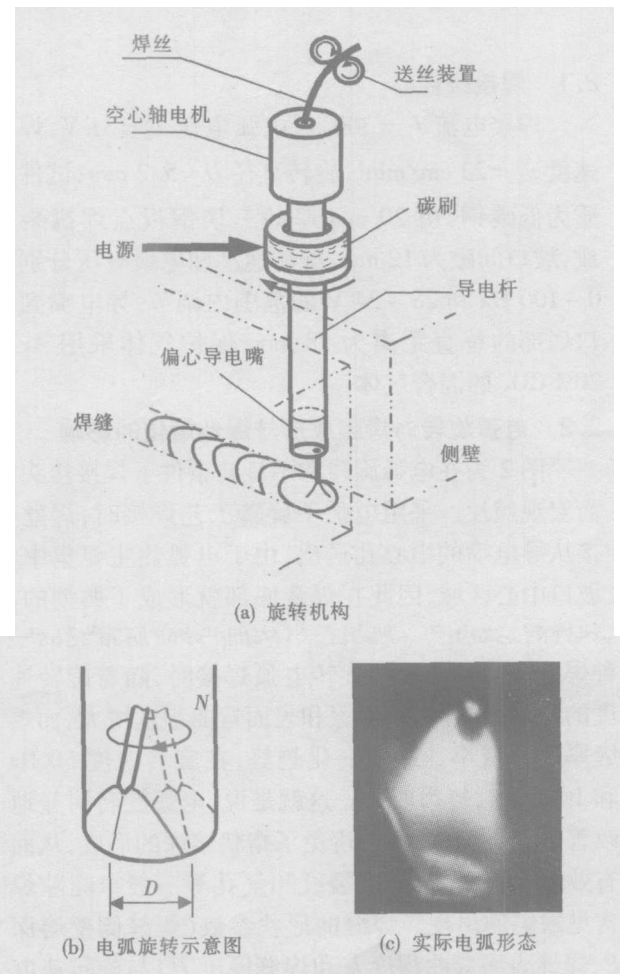


图 1 新型高速旋转电弧窄间隙焊接系统原理

Fig. 1 Principle of rotating arc welding system

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面保持滑动接触,以实现电缆无缠绕下的焊接馈电。电机直接驱动导电杆和偏心导电嘴运动,并带动焊丝端部的电弧以一定直径作高速旋转。此外,导电杆上还套装了一个光电编码器,用于检测旋转速度。根据需要,旋转速度可以在 0~100 Hz 的范围内实时调节,更换不同偏心距的导电嘴可以方便地调整旋转半径的大小。因此,这种新型旋转电弧焊接系统具有运动控制精度高、结构紧凑、重量轻、噪声低等优点。

图 1b、c 分别表示了电弧旋转运动的过程,以及一个实际的 300 A/31 V 旋转电弧在接近焊缝左侧壁时的形态。由图 1b 可知,这种旋转工艺的主要参数有两个,即电弧旋转直径  $D$  和旋转速度  $N$ 。由于电弧的高速旋转,焊接熔池得到了充分的搅动,加快了对流传热过程,另一方面电弧会周期性地偏向两侧壁,因而可以在焊缝侧壁上形成足够的熔深,同时还可避免在焊缝底侧出现指状熔深,从而提高了窄间隙电弧焊接的质量。

2 焊接试验结果与分析

2.1 焊接条件

焊接电流  $I_a=300\text{ A}$ , 电弧电压  $U=31\text{ V}$ , 焊接速度  $v_w=23\text{ cm/min}$ , 旋转直径  $D=5.2\text{ mm}$ ; 试件材质为低碳钢, 由 20 mm 厚的三块钢板点焊拼装而成, 坡口间隙为 12 mm; 旋转速度和电弧电压分别在 0~100 Hz 和 28~34 V 的范围内调节; 导电嘴到坡口底部的垂直距离为 18 mm; 保护气体采用 Ar-20%  $\text{CO}_2$  的混合气体。

2.2 电弧旋转对焊缝成形与焊丝熔化的影响

图 2 为在电弧旋转和不旋转条件下焊接接头截面宏观照片。采用电弧不旋转工艺焊接时,焊丝直接从导电嘴的中心孔送出,由于电弧热主要集中在坡口中心区域,因此在焊缝底部就形成了典型的指状熔深,这也是一般混合气体保护焊时所常见的一种焊缝成形。在采用旋转电弧焊接时,随着旋转速度的增加,焊缝侧壁熔深和表面弯曲程度增大,而焊缝厚度则减小。这种变化趋势,在旋转速度 50 Hz 和 100 Hz 时较为明显。这就是说,电弧旋转明显地改善了焊缝侧壁熔深,避免了指状熔深的形成,从而有效地防止了未焊透、裂纹和气孔等一般窄间隙焊常见缺陷的出现。焊缝的形状参数(焊缝侧壁熔深  $P$ 、焊缝表面弯曲程度  $h$  和焊缝厚度  $H$ )与旋转速度  $N$  之间的定量关系,如图 3 所示。

在焊接试验过程中,还发现在送丝速度不变的

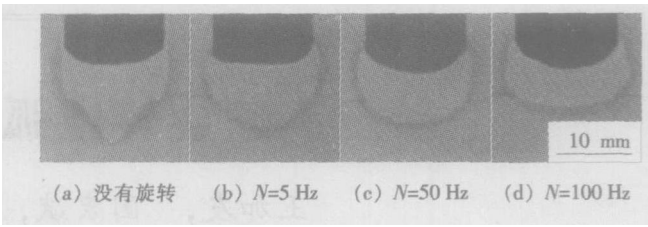


图 2 旋转速度对焊缝成形的影响  
Fig 2 Effect of rotation on bead formation  
( $I_a=300\text{ A}$   $v_w=23\text{ cm/min}$   $D=5.2\text{ mm}$   $U=31\text{ V}$ )

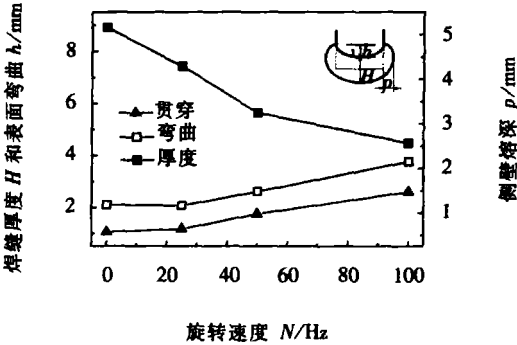


图 3 旋转速度与焊缝形状参数的关系  
Fig 3 Relationship between rotating speed and bead shape parameters  
( $I_a=300\text{ A}$   $v_w=23\text{ cm/min}$   $D=5.2\text{ mm}$   $U=31\text{ V}$ )

情况下提高旋转速度,焊接电流会出现下降的现象,其下降程度随旋转速度的变化而不同。出现这种现象的原因是,由于离心力的作用,在旋转状态下熔滴更容易脱离焊丝端部,也就是说,熔滴不需要过多的加热就可以脱离焊丝向熔池中过渡,这样过渡同样多的液态金属所需要的电弧热下降,因此焊接电流就会出现上述下降现象。鉴于此,为了保证焊接结果的可比性,在上述图 2、3 所涉及的焊接试验中,不同旋转速度下的送丝速度是不同的,以使焊接电流设定为同样的 300 A。另外,有一点需要说明的是,过快的旋转速度会使作用在熔滴上的离心力增大,容易引起较多的飞溅。

2.3 旋转电弧电压对焊缝成形的影响

电弧电压对焊缝侧壁熔深的影响如图 4、5 所示。由图 4 可见,随着电弧电压增加,一方面电弧产热增大,另一方面由于弧长增长,电弧斑点活动范围变宽,使得输入到焊缝侧壁中的热能增加,从而增大了焊缝侧壁熔深。不过,在电弧电压为 34 V 时,由于电弧搅拌以及侧壁过多热输入的作用,焊缝侧壁上的熔融金属下塌,出现了咬边现象。另外,从图 4 中还可以看出,当电弧电压增大时,焊缝表面弯曲量增加,另一方面,由于一部分热量用于增加侧壁熔

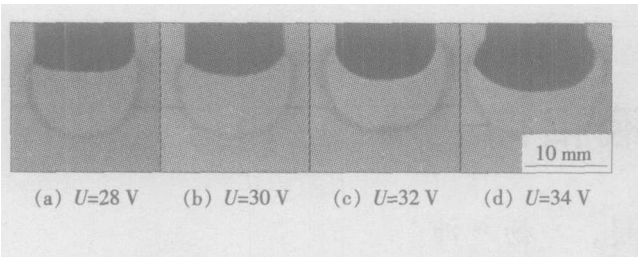


图 4 电弧电压对焊缝成形的影响 ( $N=50\text{ Hz}$ )  
Fig 4 Effect of arc voltage on bead formation at  
 $N=50\text{ Hz}$   
( $I_a=300\text{ A}$   $v_w=23\text{ cm/min}$   $D=5.2\text{ mm}$ )

深,同时弧长的增长又会增大电弧的热损失,结果导致了焊缝截面厚度的减小。焊缝的形状参数(焊缝侧壁熔深  $P$ 、焊缝表面弯曲程度  $h$  和焊缝厚度  $H$ )与电弧电压  $U$  之间的关系,如图 5 所示。

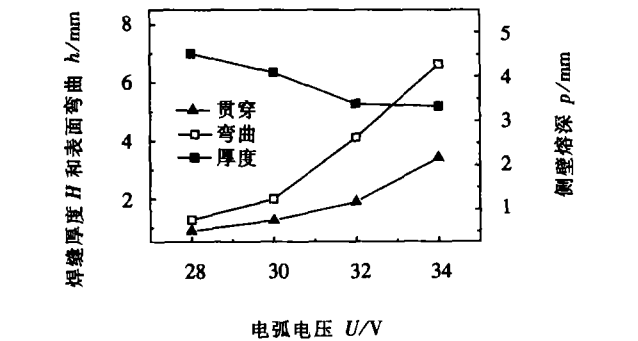


图 5 电弧电压与焊缝形状参数的关系 ( $N=50\text{ Hz}$ )  
Fig. 5 Relationship between arc voltage and  
bead shape parameters  
( $I_a=300\text{ A}$   $v_w=23\text{ cm/min}$   $D=5.2\text{ mm}$   $N=50\text{ Hz}$ )

### 2.4 多层焊接试验

根据上述试验结果,选择在旋转速度为  $50\text{ Hz}$  时,进行了窄间隙多层焊接试验,图 6 所示为三层焊时的一个焊接结果。由图 6 可见,多层焊时层与层之间融合情况良好,并且在焊缝侧壁上形成了足够的熔深,没有出现未焊透等焊接缺陷,焊缝表面成形美观。

## 3 结 论

(1) 该高速旋转电弧窄间隙焊接系统,用空心轴电机来直接驱动导电杆运动,并带动从偏心导电

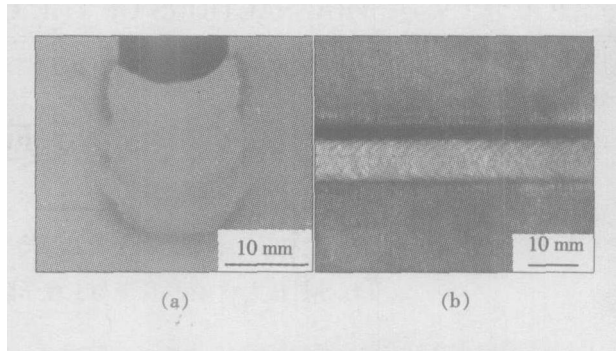


图 6 多层焊接接头截面和焊缝外观 ( $N=50\text{ Hz}$ )  
Fig 6 Multi layer bead section and weld appearance  
( $I_a=300\text{ A}$   $v_w=23\text{ cm/min}$   $D=5.2\text{ mm}$   $U=31\text{ V}$ )

嘴送出焊丝端部的电弧作高速旋转,使得焊炬更小、更轻,而且旋转噪声小、运动控制精度高。

(2) 焊接试验结果表明,随着旋转速度和电弧电压增加,焊缝侧壁熔深和焊缝表面弯曲程度增大,而焊缝截面厚度则下降;当旋转速度增大时,作用在熔滴上的离心力增大,从而加快了熔滴过渡过程,使得同样电弧热输入条件下的焊丝熔化速度得到了提高。

(3) 该旋转电弧焊接工艺,能有效地避免指状熔深和侧壁熔透不足等不良焊缝成形,明显地提高了窄间隙电弧焊接质量和焊接熔敷效率。

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### **$\text{Si}_3\text{N}_4$ ceramics brazing with composite soldering materials**

ZHANG De-ku, WU Ai-ping, ZOU Gui-sheng (Department of Materials Science and Engineering, Nanjing University of Science and Technology, Nanjing 210094, China). p59–61

**Abstract** Brazing of  $\text{Si}_3\text{N}_4$  ceramics was achieved with composite soldering materials of Ag-Cu-Ti and TN. SEM microstructures of joints showed that there was no reaction between TN particulates and Ag-Cu eutectic matrix, but the interface between them was tight. The TN particulates are generally homogeneous in the weld which is analogous to metal matrix composites. The diffusion ability of Ti is enhanced due to the strong capillary actions between the TN particulates and the liquid Ag-Cu matrix alloy, which enables Ti to diffuse sufficiently to the interfaces between the brazing materials and the substrates, on which dense and solid reaction layers are formed. Shear results of joints show that joint strength can be increased obviously in a certain range with composite soldering materials.

**Keywords** composite soldering materials; brazing;  $\text{Si}_3\text{N}_4$  ceramics; joint strength

### **Study on shear strength of soldered joints of BGA packaging devices**

XUE Song-bai<sup>1</sup>, HU Yong-Fang<sup>1</sup>, YU Sheng-lin<sup>2</sup> (1. College of Materials Science & Technology, Nanjing University of Aeronautics & Astronautics, Nanjing 210016, China; 2. The 14<sup>th</sup> Research Institute, China Electronics Technology Group Corporation, Nanjing 210013, China). p62–64

**Abstract** Shear strength of BGA packaging device joints with Sn-Pb eutectic solder were studied in the paper using Micro joints Strength Tester, and compared BGA joints shear strength with different diameters. The results indicate that in the same conditions, the bigger BGA diameter is, the smaller the shear strength is. The shear strength of BGA joint with eutectic solder is higher than that of tin-lead alloy itself.

**Keywords** BGA; shear strength; eutectic solder

### **A new rotating arc process for narrow gap MAG welding**

WANG Jie-you, GUO Hong-bin, YANG Feng (School of Materials Science and Engineering, Jiangsu University of Science and Technology, Zhenjiang 212003, China). p65–67

**Abstract** This study develops a new high-speed rotating arc system to weld narrow gap joints. In this system, an electrode wire passes through the hollow axis of motor and then stretches out from an eccentric nozzle. The hollow-axis motor drives the offset nozzle and rotates the arc on the tip of wire at high speed, so as to ensure enough penetration into the sidewalls in narrow gap welding. Welding experimental results show that the rotating arc system can stably and reliably operate at different rotation frequencies and diameters; this process obviously improved the penetrations into sidewalls and bottom side of bead, and simultaneously

raised the burn-off rate of electrode wire.

**Key words** narrow gap welding; rotating arc; weld formation; MAG welding

### **Liquid spreading and microstructure of Ti/Cu eutectic reaction**

WU Ming-fang, YANG Min, ZHANG Chao, MA Cheng, YANG Pei (Department of Materials Science and Engineering, Jiangsu University of Science and Technology, Zhenjiang, Jiangsu 212003, China). p68–71

**Abstract** The liquid spreading and structure of Ti/Cu eutectic reaction couples were primarily studied. The results showed that the spreading behaviors are remarkably different with the varied base metals and reactants. When Ti as the base metal, the spreading zone of the eutectic liquid phase is relatively regular circle-like and the contact angle is smaller. When Cu as the base metal, the spreading zone of the eutectic liquid phase is not regular, a resorption phenomenon appears. Different assembled Ti/Cu eutectic reaction couples will affect the formation and spreading rate of the liquid when Ti as the base metal and Cu as the reactant. The dissolution of Cu is quick under the condition of this work, and Cu particle is dissolved completely with holding time of 120 s, but it will spend 2 100 s for Ti particle dissolved entirely at the same condition. The intermetallic compounds are TiCu,  $\text{Ti}_3\text{Cu}_4$ ,  $\text{Ti}_2\text{Cu}$  and  $\text{TiCu}_4$ . Ti/Cu/Ti contact reactive brazing.

**Key words** Ti/Cu eutectic reaction; dissolution; spreading; microstructure

### **Effects of lead-free solder on the tensile strength of QFP micro joints soldered with different pitches**

HU Yong-fang<sup>1</sup>, XUE Song-bai<sup>1</sup>, SHI Yi-ping, YU Sheng-lin<sup>2</sup> (1. College of Materials Science & Technology, Nanjing University of Aeronautics & Astronautics, Nanjing 210016, China; 2. 14<sup>th</sup> Research Institute, China Electronics Technology Group Corporation, Nanjing 210013, China). p72–74

**Abstract** The tensile strength of QFP was tested by micro joint tester and the effects of pitch numbers, solder paste composition on the mechanical properties of QFP soldered joints were studied in this paper. The fracture micrograph of joint was also analyzed by means of SEM, and the results indicate that for the same pitch numbers, the tensile strength of the QFP soldered joint with SnAgCu solder paste is larger than that with SnPb solder paste. With the same solder paste composition, the tensile strength of the QFP soldered joint with 48 pitches is lower than that with 100 pitches.

**Key words** quad flat packaging; micro joint; tensile strength

### **Interface strengthening process of Cr plating layer by plasma beam**

WANG Ke-hong, ZHANG Chun-yang, ZHU Ping, Guo Min-le, ZHU Wu-ying (Department of Materials Science and Engineering, Nanjing University of Science and Technology, Nanjing 210094, China). p75–77