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7A52铝合金搅拌摩擦焊的焊缝成形

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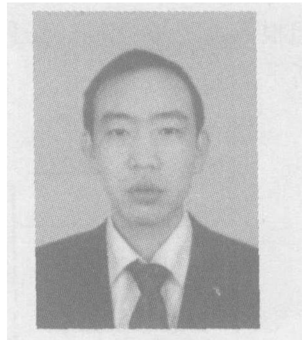

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摘 要: 针对 7.6 mm厚的 7A52铝合金, 研究了搅拌头的形状和焊接工艺参数对焊缝成形的影响, 分析了搅拌摩擦焊缺陷产生的原因。结果表明, 搅拌头的形状决定了焊接时焊缝成形的旋转速度范围; 搅拌头旋转速度、焊接移动速度、焊接倾角、搅拌头轴肩压入被焊接件表面深度等都对搅拌摩擦焊焊缝成形有重要影响, 只有合适的工艺匹配才能保证焊缝成形良好。

关键词: 铝合金; 搅拌摩擦焊; 焊缝成形

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0 序 言

7A52铝合金是一种高比强度材料, 其熔点、比重较低, 与氧的亲和力大, 热传导系数大。焊接此种材料常用的方法为 MIG(Melting inert gas)焊, 但焊接过程中易产生气孔、裂纹等缺陷, 焊接变形大, 接头性能大大降低。利用搅拌摩擦焊 (Friction stir welding, FSW)技术可以更好地保持基体材料的力学性能, 焊接变形小, 残余应力低, 并且能够减少或消除熔焊时产生的焊接缺陷。

搅拌摩擦焊 (FSW)作为一种新型焊接技术, 是由英国焊接研究所于 20世纪 90年代初发明的一种固态塑性连接方法[1], 近年来在低熔点金属材料的焊接研究中受到很高重视。它是利用一种带有焊针 (pin)和轴肩 (shoulder)的特殊形状搅拌头对工件进行搅拌摩擦, 通过焊针的搅拌摩擦过程和轴肩与材料摩擦产生的热量使焊接接缝处材料达到热塑性变形状态, 在轴肩的顶锻压力作用下达到固态连接。

影响搅拌摩擦焊焊缝成形质量的主要因素是焊接过程中搅拌摩擦的发热量和待焊材料在搅拌头作用下的塑性流动过程, 它与搅拌头的形状、焊接工艺参数有关。文献 [2~5] 分别对 LY12、LF6、2024铝合金进行了 FSW 研究, 作者针对 7A52铝合金, 讨论了搅拌头和焊接工艺参数对焊缝成形的影响。

1 试验材料及方法

试验材料选用厚度为 7.6mm的 7A52铝合金板材。材料状态为锻后热处理, 热处理工艺为 460 ℃×1 h, 室温水淬; 120 ℃× 24 h 人工时效。表 1为该材料的化学成分。

表 1 7A52铝合金的化学成分 (质量分数, %)

Table 1 Chemical composition of 7A52 aluminium alloy

Zn	Mg	Mn	Cr	Zr	Ti	Cu	Fe	Si	Al
4.35	2.40	0.35	0.20	0.10	0.12	0.12	≤0.30	≤0.25	余量

FSW焊缝成形试验在改装的焊接设备和自制的夹具上进行。试验中采用三种不同规格的螺旋形搅拌头, 在不同的焊接工艺参数下施焊, 直接观察焊缝表面成形情况并利用金相显微镜对表面成形良好的焊接接头进一步观察有无缺陷, 分析研究搅拌头形状和焊接工艺参数对焊缝成形的影响。

2 试验结果及分析

2.1 搅拌头形状对焊缝成形的影响

在搅拌摩擦焊过程中, 搅拌头设计是搅拌摩擦焊技术的核心。搅拌头的形状和尺寸对摩擦产热及金属的塑性流动状态有重要作用, 结构理想的搅拌头会提高焊接区摩擦产热功率, 使焊缝金属达到热塑性状态而易于流动, 焊接工艺性好。目前搅拌头的形状主要有圆柱形、圆锥形 (锥度较小)、螺旋形及偏心式[5]。其中螺旋形搅拌头在旋转的同时, 产生向下的压力, 更有利于焊缝金属的焊合及成形, 因此在试验中采用螺旋形搅拌头, 其外形示意图如图 1所示, 它包括三个部分, 夹持部分、轴肩部分

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及螺旋焊针。由于螺旋焊针是影响焊接成形的重要部分,是搅拌头的核心,因此在试验中采用了三种不同规格的螺旋形搅拌头,其夹持部分和轴肩部分完全相同,而螺旋焊针略有差别,分别记为A型、B型、C型。其中A型与B型焊针的锥角 α相同,而根部直径 D 不同; B型与C型焊针的锥角 α不同,但根部直径 D 相同。三种焊针的具体参数如表 2所示。

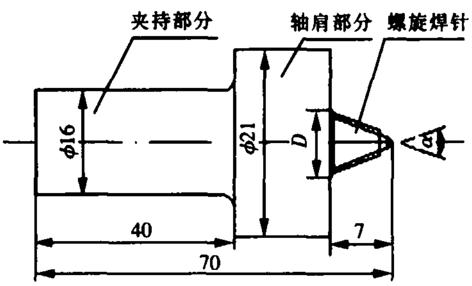

图 1 螺旋形搅拌头外形示意图

Fig. 1 Scheme of rotating tool

表 2 三种螺旋焊针参数比较

Table 2 Parameters of screw pins

搅拌头类型	根部直径 D/mm	倾斜锥角 α(°)
A型	7.5	40
B型	7.0	40
C型	7.0	60

在研究搅拌头形状影响焊缝成形的试验中,固定焊接速度为 60mm/min,焊接倾角为 2°,轴肩压入被焊接件 0.15mm,通过改变搅拌头的旋转速度来观察焊缝是否成形。表 3列出了相应的试验结果。

表 3 不同搅拌头的焊缝成形试验

Table 3 Formation test of different rotating tools

搅拌头类型	搅拌旋转速度 n/(r·min^{-1})						
	300	375	475	600	950	1 180	1 500
A型	○	○	○	×	×	×	×
B型	/	○	○	○	○	○	○
C型	/	/	/	断	○	○	○

注: 表中“○”表示焊缝成形; “×”表示焊缝未成形; “断”表示搅拌头断裂; “/”表示根据实际焊接情况困难,认为不宜焊接。(下列各表中符号含意与此表中相同)

根据表中的试验结果可以看出,搅拌头的形状直接决定着搅拌摩擦焊的焊缝成形时的旋转速度范围。对于根部直径 D 较大的A型搅拌焊针,其对应的焊缝成形时的旋转速度较低,在旋转速度较高时难以成形;对于倾斜锥角 α较大的C型搅拌焊针,其对应的焊缝成形时的旋转速度较高,在速度较低时由于焊针强度不够而难以焊接;对于根部直径 D 和倾斜锥角 α均适中的B型搅拌焊针,几乎可以在全部的焊接旋转速度范围(300~1 500 r/min)内焊接成形。

搅拌摩擦焊接过程中能否形成良好的焊接接缝,决定性因素是搅拌头的热输入量和被焊金属的热塑性流动状态。对于根部直径较大的A型搅拌焊针,其表面积大,热输入量足以使焊缝区域的材料达到热塑性状态,但相应的形成焊核区域的材料也增多。当搅拌头以较低速度旋转时,热塑性状态的金属能够随着搅拌头流动,形成良好的焊接接缝。当搅拌头高速旋转时,材料的塑性流动难以与搅拌头旋转的速度同步,从而在试样表面搅拌头的旋出侧留下一明显的沟槽。如图 2所示。对于倾斜锥角较大的的C型搅拌焊针,其表面积小,热输入量略小,但形成的焊核区域也较小,热量更集中,热塑性状态的金属是在较小的区域内流动,因此流动性好,在搅拌头高速旋转时焊缝成形性好。但在搅拌头旋转速度较低时(低于 600 r/min),焊针周围的材料软化不足,加上搅拌头螺旋焊针强度不够而发生断裂。而采用螺旋焊针直径 D 为 7.0mm、倾斜锥角 α为 40°的B型搅拌头时,既保证了螺旋焊针足够的强度不会断裂,又避免了搅拌区断面面积过大在高速旋转时成形难的问题,从而能使焊缝在较高的搅拌旋转速度范围内成形良好。

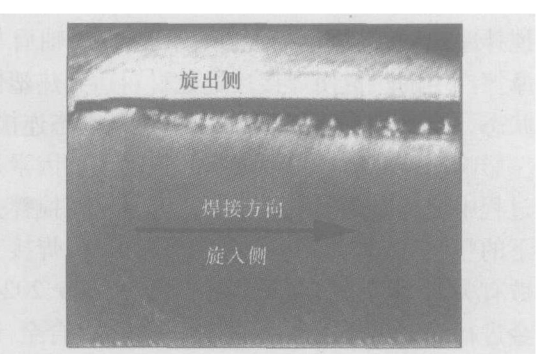

图 2 焊缝表面的沟槽缺陷

Fig. 2 Groove in weld surface

2.2 焊接工艺参数对焊缝成形的影响

在板状试样的搅拌摩擦焊接过程中,影响焊缝成形的焊接工艺参数有搅拌旋转速度、焊接速度、搅

拌头轴肩压入被焊接件表面深度、焊接倾角等。文献[6]指出，对于特定的材料，存在一个最佳力学性能规范区和最佳焊缝成形规范区，通常最佳焊缝成形规范区要比最佳力学性能规范区范围要宽。因此试验采用焊接成形规范区较宽的 B型搅拌头研究焊接工艺参数对焊缝成形的影响。

2.2.1　搅拌旋转速度和焊接速度对焊缝成形的影响

试验过程中固定焊接倾角为 2°，轴肩压入被焊接件表面为 0.15mm。焊接速度在 30～235mm/min范围内选取了六个值，而搅拌旋转速度选择了高转速的 1 500 r/min、较高转速的 950 r/min和较低转速的 475 r/min三个值进行试验，试验结果如表 4所示。

表 4　不同搅拌转速和不同焊接速度的焊缝成形试验

Table 4　Formation test in condition of different rotate speeds and different welding speeds

搅拌旋转速度 n/(r·min^{-1})	焊接速度 v/(mm·min^{-1})					
	30	60	95	118	150	235
475	Ï	Ï	Ï		◎	/
950	Ï	Ï	Ï	Ï		/
1 500	⊙	Ï	Ï	Ï	Ï	

注：表中“Ï”表示焊缝虽然能够成形，但表面较粗糙；“◎”表示表面成形，但焊缝内部有“隧道”形缺陷；“⊙”表示焊缝成形，但内部组织过烧。

由表中结果可知，只有选择合适的搅拌旋转速度与焊接速度才能使焊缝成形良好。在较低的旋转速度下，对应使焊缝成形的焊接速度范围较窄，而更高的旋转速度可使焊缝在较宽的焊接速度范围内成形良好。如前所述，焊缝能否成形主要取决于搅拌摩擦焊接过程中的热输入量和焊缝金属的热塑性流动状态。提高搅拌旋转速度和降低焊接速度，实际上都是提高热输入量、增加金属塑性流动的过程。在其它条件不变的情况下，当搅拌头的旋转速度为 475 r/min时，由于插入焊件中的搅拌头螺旋焊针部分产生的摩擦热少。只有在较低的焊接速度时(30～95 mm/min)才能保证有足够的热输入量使焊缝成形良好，图 3是成形良好的焊缝金属表面的照片。当焊接速度增加至 118 mm/min时，焊缝虽然能够成形，但由于热输入量的减少，塑性金属的流动性差，焊接表面变得粗糙，如图 4所示。当进一步增加焊接速度至 150 mm/min时，不仅焊接表面粗糙，而且在焊缝内部会产生“隧道”形缺陷，如图 5所示。因此可以认为，118mm/min的焊接速度是搅拌旋转速度在 475 r/min时焊缝能够成形的临界焊接速度，只有在低于此值时焊缝才能够成形，而高于此值时焊缝不能够成形。相应地，当搅拌旋转速度为 950 r/min时，临界焊接速度为 150 mm/min；当搅拌旋转速度为 1 500 r/min时，临界焊接速度为 235 mm/min。即随着搅拌头旋转速度的增加，临界焊接速度也相应地变大。另外，焊接速度还影响着单位长度上焊缝吸收的热量，搅拌旋转速度一定而焊接速度过慢时，单位长度焊缝上获得的热量过多，使焊缝温度接近铝合金的熔化温度而出现组织过烧。例如当搅拌旋转速度为 1 500 r/min，焊接速度为 30 mm/min时，焊缝金属内部就有此现象，如图 6所示。

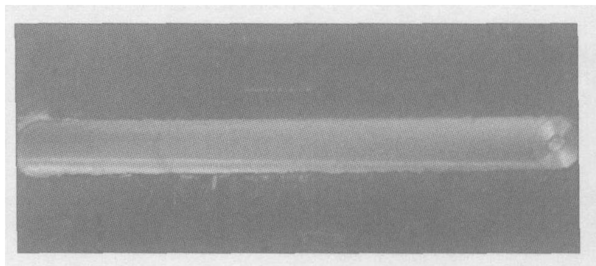

图 3　成形良好的焊缝

Fig. 3　Well shaped weld

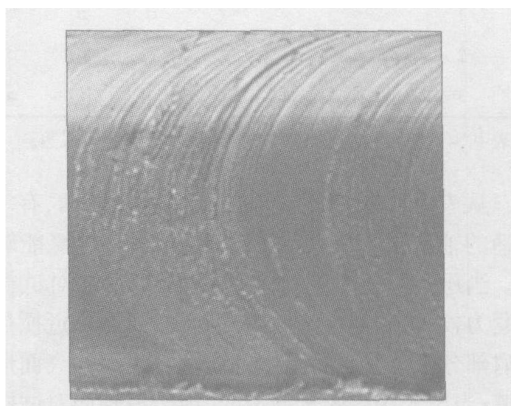

图 4　粗糙表面

Fig. 4　Coarsened welding line

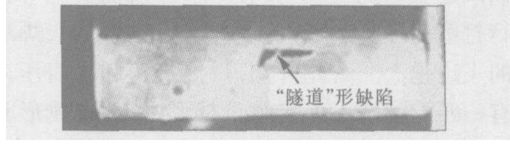

图 5　隧道型缺陷

Fig. 5　Tunnel defect

2.2.2　焊接倾角和轴肩压入被焊接件表面深度对焊缝成形的影响

除搅拌旋转速度和焊接速度外，搅拌头轴肩压入被焊接件表面深度和焊接倾角对焊缝成形也有重要影响。在试验过程中，固定搅拌旋转速度为

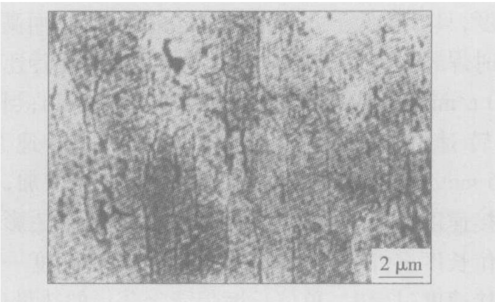

图 6 过热组织

Fig. 6 Overheated structure

950 r/min,焊接速度为 60 mm/min。当焊接倾角分别取 1°、2°、3°时,通过调整轴肩压入被焊接件表面深度在 0~0.25 mm 内变化来测定它们对焊缝成形的影响。表 5 列出了相应的试验结果。

表 5 不同焊接倾角和轴肩压入被焊接件表面深度的焊缝成形试验

Table 5 Formation test in condition of different welding obliquity and different shoulder pressing workpiece depth

焊接倾角 γ/(°)	轴肩压入被焊接件表面深度 h/mm					
0	0.05	0.10	0.15	0.20	0.25	
1	×	×	○	¤	¤	¤
2	×	×	×	○	¤	¤
3	×	×	×	×	○	¤

注:表中"¤"表示焊缝虽然能够成形,但焊缝两侧出现飞边。

从表中可以看出,对应一定的焊接倾角,有一个合适的轴肩压入被焊接件表面深度,使焊缝能够成形。当压入深度小于此值时,由于沿轴向对试样的压紧力较小,热塑性金属向上挤出,焊缝靠近搅拌头轴肩部分由于得不到足够的金属补偿而在表面形成沟槽;当压入深度大于此值时,由于沿轴向对试样的压紧力过大,与焊接头凸肩接触的被焊接件表层金属发生强烈的热塑性变形而沿轴肩边缘溢出,焊缝表面凹进及两侧出现毛刺甚至飞边,需要在焊接后进行打磨清理毛刺或飞边。压入深度越大,焊缝两侧的飞边越大。由此可知,焊接倾角和轴肩压入深度有一匹配关系。焊接倾角越大,使焊缝成形时轴肩压入被焊接件表面深度越大。对应焊接倾角 1°、2°、3°时焊缝成形良好的合理的轴肩压入被焊接件深度分别为 0.10 mm、0.15 mm、0.20 mm。图 7 是焊接倾角为 2°,轴肩压入深度由 0.10 mm 变化至 0.15 mm 时的焊缝成形情况。从图中可以看出,在压入深度为 0.10 mm 时,焊缝不能够成形,在焊缝旋出侧有沟槽缺陷。当加大压入深度至 0.15 mm 时才能形成良好的焊缝表面。

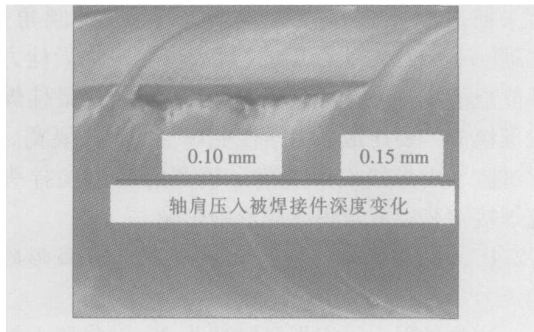

图 7 轴肩压入深度由浅到深时焊缝成形变化情况

Fig. 7 Formation of weld changed with depth of shoulder

3 结 论

(1) 搅拌头形状对焊缝成形有重要影响。对于 7.6 mm 厚的 7A52 铝合金板材,采用根部直径为 7.0 mm、倾角为 40°、长为 7 mm 的 B 型螺旋焊针进行焊接时的焊接成形区域更宽。

(2) 搅拌摩擦焊接过程中,搅拌旋转速度与焊接速度是影响热输入量和焊缝金属热塑性流动状态的重要因素,因此只有选择合适的搅拌旋转速度与焊接速度才能使焊缝成形良好。

(3) 对于一定的搅拌旋转速度,有一临界焊接速度,只有在低于此值时焊缝才能够成形良好,而高于此值时焊缝不能够成形。

(4) 轴肩压入深度和焊接倾角必须相互匹配才能使焊缝成形良好。对应焊接倾角 1°、2°、3°时的轴肩压入深度分别为 0.1 mm、0.15 mm、0.2 mm。

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NiFeC filler metal was usually developed with the "trial and error" method which wasted a lot of time and efforts. A model was developed for analysis and prediction of correlation between input parameters (welding parameter and content of filler metal) and bend strength in WC-30Co/NiFeC/45 steel TIG welding process using artificial neural network (ANN). The model was based on multiplayer back propagation neural network and trained with data sets from experiments followed by data normalization. Mean squared error of this model was analyzed. The bend strength was further predicted using the trained ANN model. The results showed that when joints welded with filler metals containing 0.6wt% or 0.8wt% C, and Ni/Fe ratio in the range from 1.9 to 2.7, were obtained and higher bend strength could be reached. The ANN model could be well used to estimate the effect of parameters on bend strength of WC-30Co/NiFeC/45 steel TIG welded joints, superior to conventional techniques.

Key words: Ni/Fe ratio; artificial neural network model; bend strength; WC-Co; tungsten inert gas welding

Numerical simulation of stress field of manual swing welding on basis of cluster heat source

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Abstract: The numerical simulation of stress field after welding of manual swing welding was done using the cluster heat source which was obtained on basis of the energy conservation law. The regularities of distribution of longitudinal residual stress and transverse residual stress were attained. Moreover, the rationality of the cluster heat source was proved by the flat experiment.

Key words: manual swing welding; cluster heat source; numerical simulation; stress field

Influence of variable polarity plasma arc shape on arc force

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Abstract: The rules of arc shape and mechanical characteristic variated with the variation of the welding parameters and the mechanical characteristic of the variable polarity plasma arc were investigated. It was proved that the combined plasma arc tended to form the double arc using the high-speed photograph and by detecting synchronously force and current of the arc. The experimental results had great indicative significances to the technology stability and process control in the variable polarity plasma arc welding on middle thickness aluminum plate.

Key words: varialbe polarity plasma arc welding; arc force; arc shape

Ending progress in vertical-up variant polarity plasma arc welding with keyhole

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Abstract: The regulation of ending progress in variant polarity plasma arc welding with keyhole was studied. The welding current, welding speed and the plasma gas flow rate were the most important parameters in the ending stage. The arc crater could be successfully filled by increasing wire feed speed, reducing ion gas flow rate as well as welding speed. The welding parameters in ending stage had their best ranges for material with different thickness. The weld mechanical properties of the joint at the end of the weld were not less than that at the middle of the weld.

Key words: variant polarity; plasma welding; ending process; aluminum alloys

Microstructure and properties of 20 steel pipe joints by transient liquid phase bonding and high temperature brazing

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Abstract: 20 steel pipes were joined with a convention nickel base brazing filler metal BNi2 and a novel iron-nickel base foil, and the mechanical properties and microstructure of them were investigated using scanning electron microscope, energy dispersive X-ray analysis and electron probe microanalysis. The results showed that BNi2 brazing produced Ni solid solution joints with silicide precipitates and heterogeneity composition. In contrast, however, transient liquid phase bonding using iron-nickel base foil resulted in homogenous joints with microstructure and composition similar to the parent metal and free of silicide precipitates. Mechanical tests showed that bonding properties of joints made using iron-nickel base foil were superior to those obtained using BNi2. When the iron-nickel base foil was used, bonding toughness was near parent toughness.

Key words: 20 steel pipe; brazing; transient liquid phase bonding; mechanical properties

Weld bead shaping of friction stir welded 7A52 aluminum alloy

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Abstract: Effect of the rotating tool figuration and welding parameters on welded bead shaping of friction stir welded 7.6mm 7A52 aluminum alloy was investigated, and the reason causing weld defect was analyzed. The results showed that the range of the rotating tool's speed in which the weld bead could shape well was decided by the rotating tool's figuration. Furthermore, the parameters including the rotating tool's speed, welding speed, welding obliquity and shoulder pressing depth into the workpiece had very important effect on the weld bead shaping. The weld bead could shape well only when the welding parameters matched well.

Key words: aluminum alloy; friction stir welding; weld bead shaping

Quality prediction of alternating current flash butt welding of rail based on improved back propagation neural network

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Abstract: An improved back propagation (BP) neural networks model was proposed based on the presented by Liu Guodong. With LabVIEW, a high speed sampling software was programmed, and by sampling the welding current, voltage and displacement of welding procedure, orthogonal methodology experiment of U71Mn rail with high frequency, the weld quality characteristic values were obtained, which were the percentage of the flashing time of which is before the accelerated flashing stage, the percentage of the flashing time of the accelerated flashing stage, the power input of weld, the welding time and the flashed length of rail as input data of the rail weld impacted quality BP neural network prediction model. The prediction model contained 5 units in the input layer, 14 units in the hidden layer. The prediction accuracy of the model trained with 17 samples of 27 samples designed by adopting orthogonal methodology was 90% using the other 10 samples.

Key words: alternating current rail flash butt welding; improved back propagation neural network; rail weld quality impacted; prediction

Numerical control cutting of welding groove for intersecting of pipe and cone

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Abstract: According to spatial analytic geometry, the mathematical model of intersecting of pipe and cone was established. The geometry shape of intersecting curve welding groove at the end of pipe was described in parameters equation. The mathematical model could be used in flame numerical control (NC) pipe cutting machine, and the machine's three axis could move together. The movement of NC cutting of welding groove for intersecting of pipe and cone was also analyzed. The torch movement was divided into three axis motion: rotation around the pipe, travel along the pipe, and bevel in axis section. The parameters for NC cutting such as intersecting curve, dihedral angle, torch bevel angle were expressed in parameters equation. And transition cutting was studied in order to solve small angle problem, and parameters in transition cutting were also given. The results of practice showed that the parameters of welding groove met the requests of American Petroleum Institute criterion.

Key words: intersecting; welding groove; numerical control cutting; cutting torch; curved surface

Diffusion welding process of aluminum matrix composite in low vacuum environment

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Abstract: The characteristics and mechanism of welding Al_2O_{3p} / 6061 aluminum matrix composite with direct diffusion welding and interlayer diffusion welding in low vacuum environment was investigated, and effects of temperature, holding time and other parameters on the performance of welded joints were analyzed. The results showed that there were three stages of the transform of joint strength with different temperature. At the longer holding time the higher strength could be gained. And at higher temperature, the oxide film was crumbled by pressure and liquid metal, and this improved the quality of welded joint.

Key words: aluminum matrix composite; direct diffusion welding; interlayer diffusion welding

Tabular welding computer aided process planning system based on client/server

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Abstract: By analyzing the actuality of computer aided process planning (CAPP) study, the characters of tabular welding CAPP system were summed up and the system based on Client/Server was developed. The structure of the system was divided into 3 layers: product layer, component layer and card layer. A new planning method was set out that was separating content from format of welding procedure. Both text-based and picture-based cards were managed by saving the outline of the procedure to database. The bidirectional compatibility interface with AutoCAD was created by file format transformation and Object Linkage and Embedded technology.

Key words: tabular welding procedure; computer aided process planning; network database