基于 RBF 神经网络的钢轨交流闪光焊接头灰斑面积预测

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摘 要：针对进口 AMS60 移动式钢轨交流闪光焊机，高速采集了 U71Mn 钢轨焊接过程中的焊接电流、电压和动端的位移，并从中提取了加速阶段闪光率、低压二及稳定烧化阶段闪光率、焊接接头的能量输入、烧化量、焊接时间、低压二及稳定烧化阶段短/断路权重因子、加速阶段的短/断路权重因子、顶锻量等 8 个影响焊接接头灰斑面积的特征量作为 RBF 神经网络预测模型的输入量，建立了 RBF 神经网络焊接接头灰斑面积的预测模型；以 29 个工艺试验焊接接头中的 19 个作为训练样本，对预测模型进行训练，以余下的 10 个作为检验样本，确定了扩展速度为 1.5 的预测模型，并采用训练后的预测模型进行预测，按铁道部标准 TB/T1632—2005 要求，预测准确率达到了 100%。

关键词：钢轨交流闪光焊；RBF 神经网络；灰斑面积；预测
中图分类号：TG115.28 文献标识码：A 文章编号：0253—360X(2008)02—0093—04

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0 序 言

列车运行速度的不断提高对无缝线路的质量要求也越来越高，而钢轨焊接接头的质量是无缝线路质量的关键，文献[1]采用改进的 BP 神经网络，针对 U71Mn 钢轨交流闪光焊焊接接头的落锤质量进行了预测研究，取得了较好效果，但也存在一些不足，因为焊接接头的内在质量只是影响落锤结果的一个主要方面，在外界条件一致的情况下，落锤结果可以用于钢轨焊接接头内在质量的评判，但由于钢轨的落锤结果与很多外界不确定因素有关，如文献[2]中所述的正火工艺、焊接接头的焊后打磨等。在钢轨闪光焊中，影响焊接接头质量的焊接缺陷主要有灰斑缺陷和过烧缺陷，过烧缺陷在焊后的接头无损探伤中是很容易检测出来的，而灰斑缺陷很难探伤，为此，选用焊接接头灰斑面积作为焊接接头质量的判定条件更加合理。

文献[3]中分析了进口 AMS60 移动式交流闪光焊机的优点：具有作用边自动对中、焊接接头起拱量调接方便等，从而焊接接头平顺性好，特别适合于客运专线和高速铁路建设，在欧洲得到较多应用。国内进口了一些该种焊机，为使其能够得到更好的应用，高速采集 U71Mn 钢轨焊接过程中焊接电流、电弧电压以及动端位移等焊接接头质量信息，提取有关质量特征量，进行钢轨焊接接头灰斑面积的预测研究。

径向基函数神经网络（RBF 神经网络）是在 1989 年由 Moody 和 Draken[4] 提出来的，它可以逼近任意的非线性连续函数，学习速度快，不存在局部最小问题，RBF 神经网络的优良特性使得它正显示出比 BP 网络更强的生命力，正在越来越多的领域内应用，因此作者以 RBF 神经网络为基础，建立钢轨焊接接头灰斑面积预测模型。

1 接头灰斑面积特征量确定

文献[1]针对 K 系列交流闪光焊机的高速采集数据，经过分析，提出了以加速阶段闪光率、低压二阶段闪光率、焊接接头的能量输入、烧化量、焊接时间等 5 个参数作为焊接接头落锤质量预测模型的输入，由于 K 系列交流闪光焊机和 AMS60 移动式交流闪光焊机都是交流闪光焊机，影响焊接接头质量的因素基本一致，因此，这些参数也影响着焊接接头的灰斑面积，在灰斑面积预测中也将它们作为特征量。从文献[1]的预测结果可以看出，落锤质量预测准确率不是很高，而且偏差很大，造成预测准确率低的原因除了序言中所述落锤质量与焊接过程以外的其它因素有关外，还有一个重要原因就是影响接头质量

收稿日期：2007—07—11

的特征量没有考虑完善，因此，除了确定上述参数为质量特征量外，还应考虑其它特征量。

1.1 低压二及稳定烧化阶段和加速阶段的短/断路权重因子

关于闪光稳定性特征量，文献[1]只考虑了加速阶段闪光率和低压二阶段闪光率，特征量提取不完善，原因如下。

（1）在焊接过程中，不同时刻的短路和断路对焊接接头的质量影响是不同的，在加速阶段初期和末期的一个持续时间相同的短路，前者对焊接接头的质量影响小，因为在后期的加速烧化过程中有可能把初期短路形成的火坑闪平或把不平度减小，而末期的短路就会对焊接接头的质量影响很大。

（2）短路和断路的持续时间长短对焊接接头的质量影响也是不同的。如在加速阶段，闪光率相同的两个接头，一个接头的短路和断路时间是由多个短、断路引起的，而另一个接头的短路和断路时间是由一个短或断路引起的，短或断路持续时间长，则后者内在质量容易出问题，因为若短路持续时间长，则液桥爆断后形成的火坑就大，在后期的加速烧化过程中很难把短路形成的火坑闪平；若断路时间长，则高温区域保护不好，被氧化严重，这两个方面问题都会使得氧化物不易被挤出而形成缺陷，影响焊接接头质量。

基于上述原因，提出了低压二及稳定烧化阶段和加速阶段的短/断路权重因子，并将它们作为闪光稳定性的特征量。

在这两个权重因子中，将短路和断路时刻以及短路和断路的持续时间长短两个因素对焊接接头质量的影响引入，计算公式为

$$k_{低压二}=\sum_{i=0}^{n}\frac{t_{i短路时间1}\times t_{i短路时刻1}}{t_{总时间}}+\sum_{j=0}^{m}\frac{t_{j断路时间1}\times t_{j断路时刻1}}{t_{总时间}} \tag{1}$$

式中：$k_{低压二}$为低压第二及稳定烧化阶段短/断路权重因子；n，m 分别为该阶段短路和断路的次数；$t_{i短路时间1}$为每次短路持续的时间；$t_{i短路时刻1}$为每次短路开始的时刻；$t_{j断路时间1}$为每次断路持续的时间；$t_{j断路时刻1}$为每次断路开始的时刻。

$$k_{加速}=\sum_{i=0}^{n}\frac{t_{i短路时间}\times t_{i短路时刻}}{t_{总时间}}+\sum_{j=0}^{m}\frac{t_{j断路时间}\times t_{j断路时刻}}{t_{总时间}} \tag{2}$$

式中：$k_{加速}$为加速阶段的短/断路权重因子；n、m 分别为该阶段短路和断路的次数；$t_{i短路时间}$为每次短路持续的时间；$t_{i短路时刻}$为每次短路开始的时刻；$t_{j断路时间}$为每次断路持续的时间；$t_{j断路时刻}$为每次断路开始的时刻。

从式(1)，式(2)可知，每次短/断路持续时间越长，短/断路时刻越晚，则短/断路权重因子越大，焊接接头的质量越容易出问题。

1.2 顶锻量

文献[1]是在顶锻量恒定的情况下，建立的质量预测模型，顶锻量没有作为特征量。在实际焊接过程中，即使设置顶锻量，对顶锻量进行严格控制，由于焊接接头的温度场差异，顶锻量仍然为变量，接头顶锻前高温区域越宽，顶锻量越大。而顶锻量的大小也会影响着接头的变形程度，影响着接头有害物质被排出的程度，从而影响焊接接头的内在质量，因此，也要将顶锻量作为焊接接头灰斑面积预测的特征量。

综上所述，进行焊接接头灰斑面积预测时所选用的质量特征量包括：加速阶段闪光率、低压二阶段闪光率、焊接接头的能量输入、烧化量、焊接时间、低压二及稳定烧化阶段短/断路权重因子、加速阶段的短/断路权重因子、顶锻量等 8 个参数。

2 神经网络预测模型的建立及预测

2.1 输入及输出层的确定

输入层采用 8 个参数，它们是焊接时间、输入能量、烧化量、顶锻量、低压及稳定阶段闪光率、加速烧化阶段闪光率、低压及稳定阶段的短/断路权重因子、加速烧化阶段短/断路权重因子；采用灰斑面积作为质量评判标准，因此以焊接接头的灰斑面积作为神经网络的输出层。

2.2 样本归一化处理

为了防止部分神经元达到饱和状态以及计算的方便，对于数值型的学习样本要进行归一化处理。采用的归一化处理公式为

$$\frac{X_p-X_{\min}}{X_{\max}-X_{\min}}\Rightarrow X'_p \tag{3}$$

式中：X_p（$p=1, 2, \cdots n$）为样本；$X_{\max}=\max\{X_p\}$为所有样本中的最大值；$X_{\min}=\min\{X_p\}$为所有样本中的最小值；X'_p（$p=1, 2, \cdots n$）为样本经归一化处理后结果。按照式(3)对 29 个试验样本数据进行归一化处理，得到的结果如表 1 所示。

2.3 网络的训练和预测及结果分析

RBF 神经网络的训练分为两步：第一步为无教师学习，确定输入层与隐含层之间的权值 w_1；第二步为有教师学习，确定训练隐含层与输出层之间的权值 w_2，其学习的具体过程在 MATLAB 软件中完成。在进行训练时需要确定径向基函数的扩展速度

表 1　归一化处理后的数据

Table 1　Normalized data of weld quality characteristic values

编号	焊接时间	烧化量	顶锻量	输入能量	低压阶段闪光率	加速阶段闪光率	权重系数 K_1	权重系数 K_2	灰斑面积	样本分类
1	0.261 8	0	0.038 4	0.552 8	0.423 9	0.941 7	0.448 2	0.014	0.230 8	训练
2	0.764 4	0.564 1	0.923 1	0.771 7	0.856 2	0	0.090 1	1	0.707 7	训练
3	1	0.512 8	0.807 7	0.894 5	0.502 9	0.526	0.316 8	0.488 5	0.615 4	训练
4	0.562	0.410 3	0.230 7	0.317 9	0.616 3	0.873 1	0.376 3	0.128 8	0.230 8	训练
5	0.802 8	0.333 3	0.077	0.534 2	0.612 9	0.235 3	0.314 6	0.856 8	1	训练
7	0.268 8	0.512 8	0	0.326 5	0.886 7	0.836 6	0.140 1	0.1596	0.0308	训练
8	0.298 4	0.692 3	0.192 3	0.336 4	0.876 8	0.699 7	0.061 5	0.375 6	0.323 1	训练
11	0	0.564 1	0.115 4	0.013 9	0.986 8	0.853 2	0.051 2	0.113 2	0.153 8	训练
12	0.289 7	0.615 4	0.077	0.274 7	0.891 1	0.845 9	0.072 9	0.118 1	0.123 1	训练
14	0.256 5	0.64 1	0.192 3	0.248 8	0.999 5	0.916 8	0	0.076 6	0.292 3	训练
15	0.595 1	0.717 9	0.269 3	0.455 9	0.974 5	0.951 9	0.000 1	0.039 4	0.384 6	训练
19	0.499 1	0.564 1	0.538 4	0.325 1	0.647 2	1	0.068 1	0.177 4	0	训练
20	0.692 8	0.743 6	0.730 8	0.514 3	0.254 2	0.778 3	0.991 4	0.257 9	0.230 8	训练
21	0.452	0.410 3	0.384 6	0.366 3	0.916 6	0.862 4	0.051	0.144 5	0.307 7	训练
22	0.818 5	0.871 8	0.923 1	0.653 6	0.571 6	0.911 5	0.225 6	0.084 1	0	训练
23	0.162 3	0.666 7	0.538 4	0.224 3	0.800 8	0.807 4	0.138 1	0.171 4	0.2	训练
25	0.938 9	0.666 7	0.538 4	0.931 7	0.128 1	0.962 5	0.949 2	0	0	训练
26	0.144 9	0.641	0.461 5	0.205 7	0	0.948 6	0.622	0.065 3	0	训练
27	0.764 4	0.794 9	0.692 3	0.779	0.664 9	0.936 4	0.051 8	0.147 2	0	训练
6	0.185	0.564 1	0.077	0.136 7	0.603 5	0.920 5	0.342 8	0.070 7	0.184 6	检验
9	0.256 5	0.743 6	0.115 4	0.349	0.981 8	0.308 9	0.009	0.669 4	0.738 5	检验
10	0.586 4	0.794 9	0.384 6	0.679 5	0.421 5	0.817	0.422 2	0.258 2	0.215 4	检验
13	0.069 8	0.641	0.038 4	0.258 1	0.854 3	0.961 2	0.115 1	0.004 6	0.015 4	检验
16	0.279 2	0.692 3	0.192 3	0.321 2	0.983 3	0.899 2	0.028 3	0.07	0.138 5	检验
17	0.322 9	0.692 3	0.346 1	0.396 2	1	0.820 4	0.002	0.125 5	0.369 2	检验
18	0.492 1	0.717 9	0.307 7	0.512 3	0.950 9	0.938	0.006 8	0.065	0.276 9	检验
24	0.005 2	0.435 9	0.230 7	0	0.042 7	0.921 4	0.613 3	0.064 9	0	检验
28	0.963 4	1	1	1	0.103 5	0.942	1	0.020 2	0	检验
29	0.825 5	0.846 2	0.961 5	0.814 2	0.655 1	0.447 5	0.303 3	0.592 1	0.492 3	检验

(SPREAD)，扩展速度越大，函数拟合就越平滑，但过大的 SPREAD 意味着需要非常多的神经元以适应函数的快速变化，导致计算上出现问题，因此，在进行网络训练时，不断增加 SPREAD 值，观察它对最终输出的影响，比较并确定一个最优值。

采用归一化处理后样本中的 19 个作为训练样本，其余 10 个作为检验样本进行预测，当选用不同的扩展速度时预测的灰斑面积与实际灰斑如表 2 所示。在对检验样本进行预测时，存在预测的灰斑面积结果为负数的情况，但实际情况中，灰斑面积不可

表 2　扩展速度不同时的灰斑面积预测结果及实际值（mm^2）

Table 2　Prediction result of grey-spot areas when SPREAD is different and test result

序号	1.5	2	2.5	3	3.5	4	4.5	5	实际值
1	14.6	7.2	5.6	4.8	4.2	3.9	3.7	3.5	12
2	62.3	0	3.3	5.4	6.6	7.2	7.7	8.0	48
3	17.6	39.6	34.4	31.8	30.3	29.4	28.8	28.4	14
4	0	0	0	0	0	0	0	0	1
5	18.1	19.0	18.5	18.3	18.1	18.0	18.0	17.9	9
6	25.8	29.1	28.2	27.8	27.6	27.4	27.3	27.2	24
7	16.1	29.0	27.6	26.8	26.4	26.2	26.0	25.9	18
8	0	19.8	17.7	16.6	16.0	15.5	15.3	15.1	0
9	0	0	0	0	0	0	0	0	0
10	30.0	53.7	54.4	55.1	55.5	55.9	56.1	56.3	32

能为负值,所以,当预测结果为负时都按灰斑面积为0处理。

由表2可知,在扩展速度SPREAD为1.5时,预测结果与实际结果最接近,因此,选择扩展速度为1.5。

铁标规定的灰斑面积要求为:大于20 mm^2 为不合格,小于20 mm^2 为合格。根据铁标规定,对预测结果进行整理,结果如表3所示。

表3 扩展速度为1.5时的预测结果

Table 3 Prediction result of grey-spot areas when SPREAD is 1.5

序号	预测值 s_1/mm^2	实际值 s_2/mm^2	灰斑面积误差 $\Delta s/mm^2$	准确否
1	14.6	12	2.6	是
2	62.3	48	14.3	是
3	17.6	14	3.6	是
4	0	1	−1	是
5	18.1	9	9.1	是
6	25.8	24	1.8	是
7	16.1	18	−1.9	是
8	0	0	0	是
9	0	0	0	是
10	30.0	32	−2	是

由表3的预测结果可知,采用8个特征量作为RBF网络输入时,建立质量预测模型,预测10个检验样本的灰斑面积的总误差率为22.97%,其中8个样本的预测灰斑面积误差在5 mm^2 以内,1个样本的预测灰斑面积误差在5~10 mm^2 之间,只有1个样本的预测灰斑面积误差在10~15 mm^2 之间,有相当高的预测准确率,若以铁标规定的灰斑面积要求作为判断标准,预测准确率为100%。

3 结 论

(1)运用MATLAB软件,建立了基于RBF神经网络的焊接接头灰斑面积预测模型,对焊接接头的灰斑面积进行了预测,通过对预测结果的分析,确定了扩展速度为1.5的预测模型,以铁标规定的判断标准进行预测,预测准确率达到了100%。

(2)短路和断路的时间长短以及在低压及加速阶段出现的时刻对灰斑面积有较大的影响,首次提出了低压二及稳定烧化阶段和加速阶段的短/断路权重因子作为灰斑面积预测的特征量。

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Abstract: The formation and mechanical properties of welded joint for 400 MPa ultra-fine grain steel were studied based on surface tension transfer technology, CO_2 arc welding, special narrow groove and different heat input. The results showed that the welded joint with good fusion, one side welding with back formation and narrow HAZ (heat-affected zone) (about 1 mm) was obtained with 3-4 kJ/cm heat input. The hardness and tensile strength of the joint were higher than those of the base metal. The embrittlement and softening of HAZ was not found, and the bending plasticity was qualified. The impact toughness of HAZ was about 60% higher than that of the base metal, which can be caused by the granular pearlite transition, multi-phase non-equilibrium microstructure and higher yield stress.

Key words: ultra-fine grain steel; welded joint; heat input; CO_2 arc welding

Residual stress and distortion of Al alloy panels welded by FSW

LI Hongke, SHI Qingyu, WANG Xin, LI Ting, LIU Yuan (Department of Mechanical Engineering, Key Laboratory for Advanced Materials Processing Technology Ministry of Education, Tsinghua University, Beijing 100084, China). p81—84

Abstract: FSW 6056-T6 Al alloy panel was welded by FSW and its distortion was measured. Also numerical model was established to simulate the distortion, temperature field and stress fields. The simulated temperature and distortion were compared with those of experiments. The results indicated that the panel bent down along welding direction and maximum distortion reaches 6.3 mm. Along the transverse direction, the panel bent up relatively to the longitudinal sides and the maximum displacement was 4.5 mm. There were high accordance trends of simulated distortion to the experiment. The longitudinal residual stress was asymmetric with the weld center line and it is higher on advancing side.

Key words: friction stir welding; welding distortion; numerical simulation

Microstructure and mechanical properties of K418 and 42CrMo dissimilar metal laser welding PANG Ming, YU Gang, WANG Henghai, ZHENG Caiyun (Institute of Mechanics, Chinese Academy of Sciences, Beijing 100080, China). p85—88

Abstract: The influences of welding heat input on weld of laser welding of K418 and 42CrMo dissimilar metal were experimentally investigated using continue wave Nd: YAG laser of output power 3 kW. Microstructure of the welded joint was studyed by optical microscope, scanning electron microscope, X-ray diffraction, and energy dispersive spectrometer. Mechanical properties of the weld were evaluated by hardness and tensile strength test. Results show that weld penetration of keyhole welding mode is larger than of heat conduction welding mode with constant linear heat input. Particle of rich Nb, Ti and Mo and deleted Fe and Ni and needle of rich Nb and Ti are observed in the fusion zone. The tensile strength of weld is higher than that of base metal of 42CrMo by optimizing laser welding parameters.

Key words: laser welding; heat-affected zone; K418 nickel alloy; 42CrMo steel; microstructure

Weld defect classification in ultrasonic testing basing on time-frequency discriminant features DU Xiuli[1,2], SHEN Yi[2], WANG Yan[2] (1. School of Information Engineering, Dalian University, Dalian, 116622, China; 2. School of Astronautics, Harbin Institute of Technology, Harbin 150001, China). p89—92

Abstract: According to transient property of ultrasonic signal, the discriminant pursuit method was proposed to extract local time-frequency features of defect signal and the features were fed to a probabilistic neural networks to classify the defects. During extracting features, the correlation between the incoming atom and the atoms selected before was considered to reduce the redundance among the selected atoms so that the extracted features discriminated different class of signals effectively. Finally, the defects of an electronic welded joint were classified by proposed approach, and the experimental results show that time-frequency discriminant features are appropriate for defects classification in ultrasonic testing, and can suppress the effect of grain noise. In addition, the higher accuracy can be reached if considering the correlation of the selected atoms.

Key words: ultrasonic test; discriminant pursuit; time-frequency discriminant feature; probabilistic neural networks

Prediction of area of gray-spots flaw in alternate rail flash butt welded joint based on RBF neural network LÜ Qibing, TAN Keli, LUO Deyang, TAN Hongtao (Institute of Welding, Southwest Jiaotong University, Sichuan Chengdu 610031, China). p93—96

Abstract: On the basis of imported AMS60 alternate rail flash butt welding machine, the welding current, the welding voltage and the displacement of welding procedure experiment of U71Mn rail were acquired with high frequency. Eight weld quality characteristic values such as the percentage of the flashing time of the accelerated flashing stage, the percentage of the flashing time of low voltage II and stable flash stage, the power input of weld, the flashed length of rail, the welding time, the short and broken circuit factor of low voltage II and stable flash stage and the short and broken circuit factor of the accelerated flashing stage and upsed length, which had influence on the grey-spot flaw area in the alternate rail flash butt welded joint, were used as input data of radial basic function neural network the rail weld grey-spot flaw. The prediction model whose spread rate was 1.5 was built, and according to the TB/T1632—

2005, the prediction accuracy of the model trained using 19 samples of 29 samples reached 100% using the other 10 samples.

Key words: alternate rail flash butt welding; radial basic function neural network; grey-spot area; prediction

Friction stir welding of AZ91D magnesium alloy sheet

LUO Hua, HAO Chuanyong (Institute of Metal Research, Chinese Academy of Sciences, Shenyang 110000, China). p97—100

Abstract: Friction stir welding (FSW) and gas tungsten arc welding (GTAW) were used to weld AZ91D magnesium alloy sheets with the thickness of 2.2 mm. The influence of the welding parameters on the FSW weld quality and microstructure and mechanical properties was investigated. Sound weldment was obtained at the tool rotating speed of 1 380 r/min, while the rotating speed of 1 960 r/min was too high. The microstructure of each zone showed very different features, which depends on the thermal and mechanical conditions. The hardness and strength of the stir zone were remarkably improved due to the fine recrystallized grain structure. The mechanical properties of FSW weldments which were superior to those of GTAW weldments depends mainly on heat input during the welding processing.

Key words: friction stir welding; AZ91D magnesium alloy; mechanical properties

Application of Choi-Williams distribution to electrical signals detecton in CO_2 arc welding

LUO Yi, WU Guangfeng, LI Chuntian (School of Material Science and Engineering, Chongqing Institute of Technology, Chongqing 400050, China). p101—103, 107

Abstract: Time-frequency distribution of Choi-Williams, which is the algorithm modified based on Wigner-Vill distribution, was used to study arc voltage signals acquired during CO_2 arc welding. The signals was analyzed in time-frequency domain to get the time-frequency distribution pattern. The influence of four parameters such as analysis window type and analysis window width of time and frequency on analysis efficiency of distribution pattern was discussed on the premise of smoothing factor in kernel function of Choi-Williams algorithm. And then, the concept of information entropy was introduced. The parameters of Choi-Williams distribution were optimized by information entropy calculating which is meaningful to improve the efficiency of time-frequency analysis. The result of experiment analysis shows that the time-frequency distribution of electrical signals during welding can be expressed by Choi-Williams distribution and the principle of minimum information entropy. And then, the cross term interference is inhibited effectively and better time-frequency centralizing is obtained.

Key words: Choi-Williams distribution; CO_2 arc welding; electrical signal; information entropy

Effects of local heat treatment by electron beam on microstructure and properties of TC4 titanium alloy welded joint

HU Meijuan, LIU Jinhe, KANG Wenjun, RUAN Chengyong (School of Materials Science and Engineering, Northwestern Polytechnical University, Xi'an 710072, China). p104—107

Abstract: The local heat treatment by electron beam on welded joint of 14.5 mm thick TC4 titanium alloy plate was carried out. Its influence on the microstructure, hardness and tensile properties of electron beam welded joint was investigated. Experimental results show that the crystal grain size of the base metal within the scanning field of local heat treatment grows explicitly after local heat treatment. While it is precipitated and grows along prior β grain boundary, α phase with a lamellar or acicular appearance grows into β grain from grain boundary. Because local heat treatment decreased the cooling velocity of weld metal, the acicular martensite decomposes β phase and transforms to coarser and shorter α phase, which shows an interwoven pattern. In addition, the hardness profile becomes smoother and differences between heat-affected zone and weld come to be almost eliminated. Integral properties of welded joint are equalized and increased along weld cross-section after local heat treatment. Fracture position of tensile test specimen shifts from the common zone between heat affected zone and base metal to parent metal without undergoing heat treatment.

Key words: local heat treatment; electron beam welding; TC4 titanium alloy; microstructure; tensile properties

State-of-arts of visual sensing technology to monitor laser welding process

QI Xiubin (Harbin Welding Institute, China Academy of Machinery Science and Technology, Harbin 150080, China). p108—112

Abstract: The performances of CCD camera and CMOS camera, which were used in monitoring the laser welding process, were compared. The problems and their solutions in visaul sensing for laser welding process and the common used light path to abstract the imaging signal were introduced. The characteristics of the coaxial and side visual sensing technologies and their state-of-the-arts of developments were summaried. The analyzed results showed that, the active visual sensing technology of Japan is much more advanced than that of the other countries, and the passive coaxial visual sensing technology of Germany is in the leading level in the world, and the laser welding heads with coaxial visual sensor and sending system were developed by some institute and company in Germany. The studies on the visual sensing technologies for laser welding starts relatively late, which has a vast gap with the developed coountries. At present, the visual sensing and monitoring technology for laser welding is mainly used in basic research such as study of the laser welding mechanism, and its application in production is the developing direction of the research and development of coaxial sensing technology.

Key words: laser welding; visual sensing; state-of-arts and development