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新渣系碱性焊条工艺性能综合优化

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摘　要：分析了多种国内外碱性焊条药皮渣系，设计了新的渣系．用均匀设计的思想方法和计算机软件来安排试验．选定 9种药皮组分作为自变量，把每个自变量分成 6个水平，共做了 24个焊条小样．利用计算机统计分析 7个工艺性能指标数据，结果给出了自变量与因变量之间的多项式数学模型．它们揭示出多种药皮组分对多个指标的影响规律．借助计算机和这些数学模型，做了多项指标的综合优化，得到了搜索结果．该结果为改善焊条工艺性能提供了方向．该搜索预测方法也是全面改善焊条性能的一个新尝试．

关键词：碱性焊条；工艺性能；均匀设计；优化
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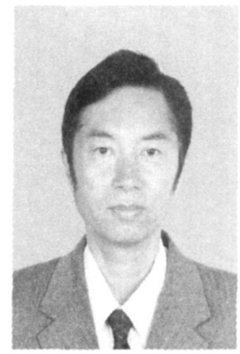
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0　序　　言

全世界对人类生存环境的重视程度越来越高，国内近年来也极为重视加强生态环境保护，不断推进节能减排工作；然而在焊接过程中不可避免地要产生一定量的焊接烟尘等有害物质，会对环境造成严重污染，也会对焊工的身心健康造成直接危害．

有资料显示[1]，在各类焊接材料有害物质（例如烟尘）的发尘量中，以埋弧焊丝发尘量最小，自保护药芯焊丝发尘量最高．在各种类型药皮焊条中，钛钙型焊条发尘量较小，其次是钛型、钛铁矿型，碱性渣系焊条的发尘量较多．在各类气保护焊丝中，药芯焊丝产生的烟尘比实芯焊丝要大．

焊接方法有多种多样，焊接材料特性却是产生发尘的根本．以碱性渣系焊条为例，通常情况下，不同的药皮组分和配方会对焊接工艺性能有极大的影响，但该药皮组分和配方同时也会对产生焊接烟尘有极大的影响．所以，在许多情况下，获得优良的焊接工艺性能与降低焊接烟尘是一个矛盾．

为了解决这一问题，文中利用中国数学会均匀设计分会推荐的计算机软件安排试验[2]，进行数据的统计分析，并充分利用这一软件进行新渣系碱性焊条工艺性能的综合优化．在影响因子很多，指标也很多的复杂情形下，探索利用现代信息技术研究焊接材料，兼顾多个方面，在获得优良焊接工艺性能的同时，降低烟尘．

1　试验方法

选择国内外 4种不同牌号的低氢型药皮焊条，利用 FEI Sirion 200热场发射扫描电子显微镜进行焊接熔渣中钙、氟、硅、锰、钾、钠、钡等元素含量的测试分析[3]，参考了日本焊条专利[4,5]及有关低烟尘焊条的国内文献[6,7]，定下渣系为 $CaCO_3$-$BaCO_3$-CaF_2-BaF_2-$CaSO_3$-TiO_2．

对上述这样一个新的药皮渣系，采用均匀设计的思想和方法及软件来安排试验．共考察了 9种药皮组分，每种组分为 6个水平，采用表 $U_{24}(6^9)$，即共做 24个焊条小样，然后通过统计回归来处理这些试验数据．具体的药皮组分种类及配方（质量分数，%）范围和试验点排列序号如表 1(钛铁、中锰等组分在试验中不算作变量，没有列入)、表 2所示．

试验中选用 H08A，φ3.2焊芯．焊条压制在 TL—25—1型压涂机上完成，采用钾钠混合水玻璃．焊接烟尘的测定[8]按照 JB/T8423—96《电焊条焊接工艺性能评定方法》进行，焊接电流为 120 A，电压为 24 V，采用直流电源，反接；稳弧、飞溅、覆盖、脱渣[3]、成形 5个工艺性能指标测定由有经验的焊工技师参照该标准，进行满分十分制的多次打分平均获得．

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表 1 药皮组分及配方（质量分数，%）

Table 1 Coating constituents and using quantities in formulas

范围	大理石 X_1	氟化钡 X_2	硅灰石 X_3	钛白粉 X_4	金红石 X_5	铝镁粉 X_6	萤石 X_7	碳酸钡 X_8	铁粉 X_9
最小值	17.44	3.77	3.61	1.33	0	0	3.97	0	0
最大值	42.9	13.52	21.56	7.17	11.05	6.15	16.94	9.01	24.71

表 2 均匀设计试验点的 9种药皮组分（质量分数，%）

Table 2 Nine coating constituent proportions of test points by uniform design

序号	大理石 X_1	氟化钡 X_2	硅灰石 X_3	钛白粉 X_4	金红石 X_5	铝镁粉 X_6	萤石 X_7	碳酸钡 X_8	铁粉 X_9
1	27.18	9.06	14.00	4.94	0	0	4.12	4.94	19.76
2	20.63	8.11	9.58	3.68	5.89	4.42	11.05	7.37	13.26
					……				
23	27.50	9.17	20.83	3.33	8.33	4.00	9.17	1.67	0
24	25.24	6.31	18.93	2.70	7.21	1.08	6.31	0	16.22

2 试验结果与分析

按照上述方法完成试验（表 3），从表 3可以知道这 24个配方样品的 7个工艺性能数据．再把配方和工艺性能指标试验数据输入计算机，采用逐步回归的统计方法，就可以分别得到 7个多项式方程．每个方程都可以定量地描述焊条药皮组分与对应的工艺性能指标间的关系．例如指标稳弧 Y_1可由下式给出

$$Y_1 = +7.408\,04 + 5.339\,61 \times 10 X_1 X_9 + 1.409\,50 \times 10^2 X_2 X_8 - 1.343\,59 \times 10^2 X_2 X_9 - 3.058\,34 \times 10 X_9 X_9 \quad (1)$$

从式（1）可以看出，大理石 X_1和铁粉 X_9的交互作用，氟化钡 X_2和碳酸钡 X_8的交互作用，都对指标稳弧 Y_1产生正相关的影响，即它们含量的增加，会使得稳弧性增加；而氟化钡 X_2和铁粉 X_9的交互作用，铁粉 X_9自身的二次项，则都会对指标稳弧 Y_1产生负相关的影响，即它们含量的增加，会使得稳弧性降低．

为说明这些结果的可靠性，分别对方程做了方差分析，证明 7个方程的显著性都为高度显著，其结果举例见表 4．从表 4中可以看出，当置信限 $\alpha = 0.01$时，统计量值 F>查表量值 $F_{(4, 19)}$，所以回归方程（1）为高度显著．

表 3 均匀设计各试验点的 7个工艺性能指标

Table 3 Seven target data of usability of electrode on test points by uniform design

序号	稳弧 Y_1（10分制分值）	飞溅 Y_2（10分制分值）	覆盖 Y_3（10分制分值）	脱渣性 Y_4（10分制分值）	成形 Y_5（10分制分值）	发尘量 Y_6 /($g \cdot kg^{-1}$)	发尘速率 Y_7 /($g \cdot min^{-1}$)
1	7.750	7.500	6.250	4.750	4.750	14.720	0.310
2	8.000	8.750	6.750	4.500	7.500	19.850	0.430
				……			
23	7.625	7.750	7.750	8.625	8.875	12.270	0.260
24	8.000	7.625	7.375	8.375	7.750	11.500	0.230

表 4 方程（1）方差分析

Table 4 Variance analysis on regressive equation (1)

方差来源	平方和	自由度	均方和	显著性
回归	$1.602\,4 \times 10$	4	$4.006\,0 \times 10^0$	当置信限 $\alpha = 0.01$时，
剩余	$5.016\,9 \times 10^0$	19	$2.640\,5 \times 10^{-1}$	F统计量值 $= 1.517\,2 \times 10$
总计	$2.104\,1 \times 10$	23	—	$F_{(4, 19)} = 4.500\,3$

3 指标优化预测

利用这些已经建立的 7个多项式方程，可以在计算机上进行 7个指标的优化搜索，如表 5和表 6为进行优化搜索时的条件设置．从表 5和表 6中可以看到，在原始 24个配方药皮组分的质量分数范围内，把每个组分在药皮中的含量设为 3个档次水平，再参考 24个配方下 7个指标的最大和最小值，将指

标合理、充分地向上设定, 最后开始在计算机上搜索, 得到优化结果, 如表 7和表 8所示.

表 5　优化搜索药皮组分配比设置 (质量分数, %)

Table 5　Given weight proportions for optimizing search coating constituents

初始/设置		大理石 X_1	氟化钡 X_2	硅灰石 X_3	钛白粉 X_4	金红石 X_5	铝镁粉 X_6	萤石 X_7	碳酸钡 X_8	铁粉 X_9
初始	最小	17.44	3.77	3.61	1.33	0	0	3.97	0	0
	最大	42.90	13.52	21.56	7.17	11.05	6.15	16.94	9.01	24.71
设置	最小	17.44	3.77	3.61	1.33	0	0	3.97	0	0
约束	最大	42.90	13.52	21.56	7.17	11.05	6.15	16.94	9.01	24.71
水平数		3	3	3	3	3	3	3	3	3

表 6　优化搜索指标设置

Table 6　Given limits for optimizing search targets

初始/设置		稳弧 Y_1 (10分制分值)	飞溅 Y_2 (10分制分值)	覆盖 Y_3 (10分制分值)	脱渣性 Y_4 (10分制分值)	成形 Y_5 (10分制分值)	发尘量 Y_6 /(g·kg^{-1})	发射速率 Y_7 /(g·min^{-1})
初始	最小	5.000	6.625	5.000	4.000	4.750	9.900	0.220
	最大	8.875	9.000	8.750	8.625	8.875	25.960	0.510
设置	最小	7.500	7.500	7.500	7.500	7.500	5.000	0.100
约束	最大	66.000	66.000	66.000	66.000	66.000	9.000	0.200

表 7　优化搜索药皮组分配比结果 (质量分数, %)

Table 7　Optimizing search results of coating constituent weight proportions

序号	大理石 X_1	氟化钡 X_2	硅灰石 X_3	钛白粉 X_4	金红石 X_5	铝镁粉 X_6	萤石 X_7	碳酸钡 X_8	铁粉 X_9
1	17.44	3.80	21.60	4.30	11.10	3.10	4.00	4.50	12.40
3	17.44	8.70	21.60	4.30	11.10	3.10	4.00	4.50	0.00
6	17.44	3.80	21.60	7.20	5.60	3.10	4.00	4.50	0.00

表 8　优化搜索指标结果

Table 8　Optimizing search target results

序号	稳弧 Y_1 (10分制分值)	飞溅 Y_2 (10分制分值)	覆盖 Y_3 (10分制分值)	脱渣性 Y_4 (10分制分值)	成形 Y_5 (10分制分值)	发尘量 Y_6 /(g·kg^{-1})	发射速率 Y_7 /(g·min^{-1})
1	7.699	7.847	7.621	9.920	9.145	8.101	0.187
3	7.957	7.859	7.562	7.668	10.828	5.504	0.138
6	7.649	7.956	8.734	7.668	11.210	5.779	0.114

从表 7和表 8中可以看到, 通过设置条件后进行搜索, 就可以得到若干个焊条药皮组分配方, 并且可以知道在这些配方下焊条 7个工艺性能指标的预测结果. 如 1号配方的脱渣性可以得到 9.92的高分, 3号配方的发尘量可以得到 5.504的低值, 6号配方的发尘速率可以得到 0.114的数据; 这些数据都比原始 24个配方中的指标数据好的多.

改变表 5和表 6中的设置条件, 如把每个组分在药皮中的含量设为 4个档次水平, 再适当改变 7个指标的最大和最小值, 就可以搜索出更多的配方, 为试验提供方向.

4　结　　论

(1) 基于均匀设计的方法及软件研究新渣系碱性焊条, 可以同时得到多个工艺性能指标对应于多种药皮组分的多项式数学模型, 从而定量地揭示出二者之间复杂的相关关系.

(2) 借助计算机和这些数学模型, 做了多项指标综合优化, 得到了具有重要参考价值的搜索结果,

为全面改善焊条工艺性能提供了方向.

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shows the best mechanical property of the brazed joint when the Ag content exceeds 3 3%, the mechanical property of the brazed joint remains stable The addition of Ag can refine the $CuAl_2$ brittle phase in the brazed seam which decreases the stress concentration and enhances the brazed joints In general the brazing filler metal with 3 3% Ag has the best comprehensive properties

Key words: brazing CuAl; ZnAl fill metal; spreadability mechanical property microstructure

Microstructures and mechanical properties of friction stir welded 2219-T87 aluminum alloy joints

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Abstract: The joint of 2219-T87 aluminum alloy plate in 8 mm thickness was obtained by friction stir welding (FSW), and the microstructures and mechanical properties of the joint were investigated The results show that the microstructure in the nugget zone (NZ) consists of refined and equiaxed grains that in the thermal-mechanically affected zone (TMAZ) consists of deformed grains and that in the heat affected zone (HAZ) consists of coarse lath grains There is an obvious interface between NZ and TMAZ at the advancing side but there is illegibility comparatively at the retreating side The precipitation phenomena in different zone are affected by friction stir welding The results of tensile properties show that the transverse tensile strength of FSW joint can reach about 70% of that of the base metal Hardness measurements show that the FSW joint is soften during welding heat affect zone has serious softening and tensile specimens fracture at the HAZ of retreating side Fractographs confirm that the fracture of the joint is the mode of ductile fracture

Key words: aluminum alloy 2219; friction stir welding; mechanical properties microstructures

Comprehensively optimizing usability of new slag system basic electrode

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Abstract: A new slag system was designed after analyzing several domestic and abroad basic slag system electrode coatings The experiments were arranged by the uniform design method and computer software Nine coating constituents were taken as independent variables and were divided into 6 levels in all 24 experiments The 7 usability target data were put into computer to analyze statistically The results give the mathematic model multinomial between independent variables and functions which indicate the influence laws of many coating constituents on many targets With computers and these mathematic models many usability targets are optimized and the searching data are got which give directions for improving usability of electrode This search/calculating method is also a new attempt for improving electrode properties in an all-round way

Key words: basic electrode; usability uniform design; optimization

Influences of LaF_3 on microstructure and performance of laser cladding layer in-situ fabricated

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Abstract: In-situ Ni-based TiC composite coatings with LaF_3 were made by laser cladding and the microstructure composition profiles microhardness wear and corrosion properties of the coatings were analyzed by using electron probe micro-analyzer (EPMA), transmission electron microscope (TEM), scanning electron microscope (SEM), microhardness instrument M-2000 Friction and Wear Tester and M398 Electrochemical corrosion systems The results show that after adding moderate rare earth LaF_3, the microstructure presents more homogeneous the fineness of grain becomes finer TiC distributes better and heterogeneous phase decreases When the content of LaF_3 is 1%, the highest microhardness is got when it is 2%, the optimal wear and corrosion resistance properties are obtained but when adding excessive rare earth LaF_3, both the microstructure and properties will get worse

Key words: laser cladding in-situ fabricated rare earth LaF_3; TiC pellet

Effect of magnetic field style on microstructure and properties of overlay deposit

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Abstract: The Fe5 alloy was overlaid on low carbon steel by plasma arc surfacing with longitudinal magnetic field The style of magnetic field was changed during surfacing which was direct magnetic field or alternating magnetic field After plasma arc surfacing with magnetic field the scanning electron microscopes wear loss test micro-hardness test were used to analyze the effect of magnetic field style on the properties of overlay deposit The acting mechanism of magnetic field style and parameters on the properties and microstructure of the deposit was researched The results indicate that the introduced DC/AC magnetic field can give an effective intervention to the properties of the deposit The active effect of AC magnetic field is better than that of DC magnetic field because the magnetic field can be controlled during AC magnetic field by alternation of magnetic field frequency The optimal result is acquired when magnetic current is 3 A and magnetic frequency is 10 Hz and the hardness of the properties is 68 HRC and wear loss is 0 031 8 g

Key words: plasma arc surfacing magnetic field style; electromagnetic stirring microstructure and properties

Influence of processing parameters on performance of friction stir spot welding with re-filling probe hole

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