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Optimized composition for bonding assistant coat in carbon steel sandwich panels

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Abstract: On the basis of the alloying theory of bonding assistant coat (BAC), taking into account of the interaction of alloy elements, the regressive equation, which relates the wetting ability of bonding assistant coat with the contents of Mn, Ni, Si, Sn, and B, was established by using quadratic regression orthogonal design of five factors. The influence of elements and their interaction on the wetting ability was analyzed. The ranges of alloy elements were optimized. The melting point of bonding assistant coat was measured by using differential thermal analysis. The results show that the interactions of Ni and Mn, Ni, and Sn can increase the wetting ability obviously and the melting point of bonding assistant coat has been decreased.

Key words: bonding assistant coat (BAC); alloy; quadratic regression; wetting ability

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1. Introduction

The BAC (bonding assistant coat) for carbon steel sandwich panels can be classified as copper alloys and silver alloys. The silver alloy as BAC has lower melting point and can wet multi-kind metals, but silver is a rare metal and very expensive, so its cost as BAC is very high. Copper and zinc are regarded as basic elements in this paper. On the basis of the alloying theory [1-4], twenty seven groups of composition are determined by using quadratic regression orthogonal design of five factors and selecting table $L_{16}(2^{15})$. After smelting these metallurgical products, the wetting ability is measured according to the national standard GB11364–89 [5].

2. Design of test

The BAC for carbon steel sandwich panels should have fine wetting ability and its melting point should be lower than that of base metal. From the point of view of composition, alloying elements should contain melting point depressant elements (MPD) and these MPDs can diffuse into base metal quickly [6-7]. To meet these demands and for referencing the theory of Zn equivalence [8], the ranges of alloying elements are determined preliminarily (shown in Table 1).

The alterable ranges of natural factors z_j are shown in Table 1. To make the coefficients unrelated, all factors are coded, and zero level (z_{0j}) and variable interval (Δ_j) are calculated, where z_{1j} and z_{2j} represent the lower limit and upper limit of factors z_j (j=1,2, ⋯, p) [9]:

$$z_{0j} = \frac{z_{1j} + z_{2j}}{2} \quad (1)$$

$$\Delta_j = \frac{z_{2j} - z_{0j}}{\gamma} \quad (2)$$

$$x_j = \frac{z_j - z_{0j}}{\Delta_j} \quad (3)$$

So the code and all factors have the following corresponding relations:

$$\begin{cases} x_j = \gamma \Rightarrow z_{2j} \\ x_j = 1 \Rightarrow z_{0j} + \Delta_j \\ x_j = 0 \Rightarrow z_{0j} \\ x_j = -1 \Rightarrow z_{0j} - \Delta_j \\ x_j = -\gamma \Rightarrow z_{1j} \end{cases} \quad (4)$$

The value of γ is determined according to the amount of factors and the test number of center points. In this paper, the value of γ^2 is 2.770. The codes of all factors are shown in Table 2.

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Table 1. Alterable range of five factors

Alterable range	z_1(Sn)	z_2(Ni)	z_3(Mn)	z_4(Si)	z_5(B)
Lower limit (z_{1j})	1	1	7	0	0
Upper limit (z_{2j})	3	3.5	9	2	0.1

Table 2. Level and code of natural factors

Factor	z_1	z_2	z_3	z_4	z_5
$\gamma(z_{2j})$	3	3.5	9	2	0.1
$1(z_{0j}+\Delta_j)$	2.60	3.0	8.60	1.60	0.08
$0(z_{0j})$	2	2.25	8	1	0.05
$-1(z_{0j}-\Delta_j)$	1.40	1.50	7.40	0.40	0.02
$-\gamma(z_{1j})$	1	1	7	0	0
$\Delta_j=(z_{2j}-z_{0j})/\gamma$	0.60	0.75	0.60	0.60	0.03
$x_j=(z_j-z_{0j})/\Delta_j$	$x_1=(z_1-2)/0.60$	$x_2=(z_2-2.25)/0.75$	$x_3=(z_3-8)/0.60$	$x_4=(z_4-1)/0.60$	$x_5=(z_5-0.05)/0.03$

In terms of the basic theory and main procedure of quadratic regression orthogonal design, the test schemes were worked out, the calculated format was listed, and the regressive coefficients of each item and square sum of each column were calculated. The results are shown in Table 3.

3. Establishment of the equation related the wetting ability with alloying elements

From Table 3, it can be seen that the significance level α of the regressive coefficients of simple items x_1, x_2, x_3, interactive item coefficients x_1x_2, x_1x_4, x_1x_5, x_2x_4, x_2x_5, x_3x_4 and the quadratic item coefficients x_3' are bigger than 0.25, so they are eliminated from the equation, the equation of wetting area $\hat{y}_w$ is obtained as below:

$$\hat{y}_w=155.47+6.73x_2-2.12x_4+5.91x_1x_3+6.98x_2x_3+5.29x_3x_5-6.14x_4x_5-4.96x_1'-9.92x_2'+9.12x_4'-4.55x_5' \quad (5)$$

Then the square sum of regression is that

$$S_1=S_{x_2}+S_{x_4}+S_{x_1x_3}+S_{x_2x_3}+S_{x_3x_5}+S_{x_4x_5}+S_{x_1'}+S_{x_2'}+S_{x_4'}+S_{x_5'}=6946.50,$$

$$f_1=10,$$

$$S_2=\sum_{i=1}^{N}y_i^2-\frac{1}{N}\left(\sum_{i=1}^{N}y_i\right)^2=9899.48,$$

$$f_2=28,$$

$$S_3=S_2-S_1=2952.98,$$

$$f_3=f_2-f_1=18,$$

$$S_e=\sum_{i=1}^{3}y_{i0}^2-\frac{1}{3}\left(\sum_{i=1}^{3}y_{i0}\right)^2=206,$$

$$f_e=2,$$

$$F_1=\frac{S_1/f_1}{S_3/f_3}=4.23>F_{0.01}(10,18)=3.51,$$

$$S_{\rm lf}=S_3-S_e=2746.98,$$

$$f_{\rm lf}=f_3-f_e=16,$$

$$F_{\rm lf}=\frac{S_{\rm lf}/f_{\rm lf}}{S_e/f_e}=1.66<F_{0.25}(16,2)=3.41.$$

The statistical results of the tests have shown that the significance level of regressive Eq. (5) is 0.01, namely the degree of confidence is 99%, and the equation is drafted very well.

The formula of quadratic item central treatment is

$$x_{ij}'=x_{ij}^2-\frac{1}{n}\sum_{i=1}^{N}x_{ij}^2=x_{ij}^2-0.743 \quad (6)$$

The formula of central treatment (6) and the formula of coding in table 2 are inserted into Eq. (5), and the result is obtained.

$$\hat{y}_w=657.6-13.78z_1^2-76.16z_1-17.64z_2^2-35.62z_2-82.42z_3+25.4z_4^2-36.53z_4-5055z_5^2-1504.5z_5+16.41z_1z_3+15.51z_2z_3+293.9z_3z_5-341z_4z_5 \quad (7)$$

4. Analysis of test factors

As the interaction of alloying elements in BAC with other elements in BAC and in base metal happens simultaneously, the influence of alloying elements on the wetting ability is relatively complex. Fig. 1 shows the curves of relationship between wetting ability and alloying elements. From Fig. 1 it can be seen that the