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RAPID OPTIMIZATION OF LASER QUENCHING PROCESS BASED ON BP NEURAL NETWORK

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The rapid optimization of laser quenching process parameters were studied. First of all, the experiment is carried out by orthogonal method, which achieves the purpose of finding the influence law of process parameters with a small number of samples. Then, the neural network modeling is used, the process parameters and the experimental results are functionally fitted, and the model is continuously revised by reducing the feedback error, and finally the prediction model with the smallest error is obtained. Finally, the genetic algorithm is used to quickly search for optimization, and based on the prediction model, population selection, crossover, mutation and iteration are used to obtain the optimal fitness and corresponding variable value.

Key words: C45 steel, laser quenching, samples, surface, hardness

INTRODUCTION

45 steel is a commonly used medium carbon steel, which has the advantages of high strength, high toughness, good plasticity and low price, and is widely used in the metallurgical industry. With the rapid development of metallurgical industry production, the requirements for surface strength and wear resistance of main parts of production equipment are also increasing. Therefore, the research on surface modification of 45 steel has important practical application prospects. Laser surface quenching can improve the hardness[1,2], wear resistance and corrosion resistance of the metal surface, and at the same time ensure the toughness inside the metal, and improve the service life of metal parts to a certain extent[3]. In this study, laser quenching of 45 steel was used to improve its surface hardness. At the same time, the process parameters of laser quenching are studied, and the optimal process parameters are quickly found through orthogonal experiments, neural networks and genetic algorithms, which reduce a large number of repeated experiments and save a lot of time and cost for the laser quenching process.

EXPERIMENTAL MATERIALS AND EQUIPMENT

The experimental equipment is JHM-1GY-400 laser, the laser wavelength is 1,06 μm, the rated average laser power is 400 W, the laser pulse frequency is 1~200 Hz (adjustable), the laser pulse width is 0,1~20 ms (adjustable), the focal length of the focusing mirror is 160 mm, and the spot diameter is 0,6 1 mm. 45 steel specifications are 100 mm × 100 mm × 8 mm.

EXPERIMENTS

According to practical experience, 4 factors and 5 levels are selected as the input vector of the neural network, and the specific factor levels are shown in Table 1.

Table 1 **Factor level table**

Level \ Factor	A	B	C	D
1	200	0,8	150	-1
2	210	1	200	-0,5
3	220	1,2	250	0,5
4	230	1,4	300	1
0	215	1,1	225	0

In Table 1, the factor A is the current, in amperes (A); the factor B is the pulse width, in milliseconds (ms); the factor C is the scanning speed, in millimeters per minute (mm·min-1); the factor D is defocusing amount in millimeters (mm). According to practical experience, the appropriate level 1-4 for each factor is selected, and the level 0 is the mean of all levels.

Table 2 is the hardness (HRC) results of the laser quenched samples. The experimental results are performed by orthogonal method. The characteristic of the orthogonal experiment is that the experimental law can be displayed with a small number of key process parameters. Using the orthogonal method to conduct experiments, it can avoid a large number of experiments and save time and cost. The experimental sample is shown in Figure 1.

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Table 2 **Orthogonal experiment**

No.	ABCD	HRC	No.	ABCD	HRC
1	1111	40	14	4231	50,8
2	1222	44,5	15	4324	55
3	1333	47,5	16	4413	58
4	1444	50,5	17	0000	45
5	2123	46,5	18	2222	43
6	2214	45,5	19	3333	46
7	2341	52,5	20	4444	53
8	2432	54	21	1000	46
9	3134	50,5	22	2111	48,3
10	3243	55,8	23	3222	50,2
11	3312	49,4	24	4333	52
12	3421	50,9	25	0444	51,5
13	4142	50			

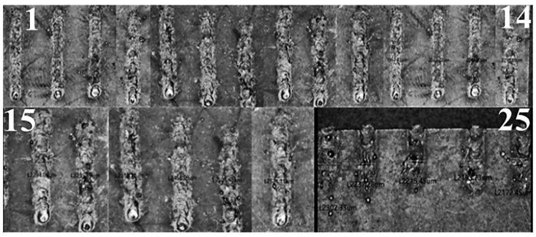

Figure 1 laser quenching sample

NEURAL NETWORK MODELING

BP neural network is a multi-layer feedforward neural network. The learning process consists of two processes: forward propagation of signals and back propagation of errors. During forward propagation, input samples are passed in from the input layer, processed layer by layer in each hidden layer, and then transmitted to the output layer. If the actual output of the output layer does not match the expected output, the back-propagation stage of the error begin. Error back propagation is that the output error is back-propagated layer by layer through the hidden layer to the input layer in some form, and the error is distributed to all units in each layer. This process is repeated until the error of the network output is reduced to an acceptable degree, or the pre-set number of learning is reached. The three-layer BP network is shown in Figure 2.

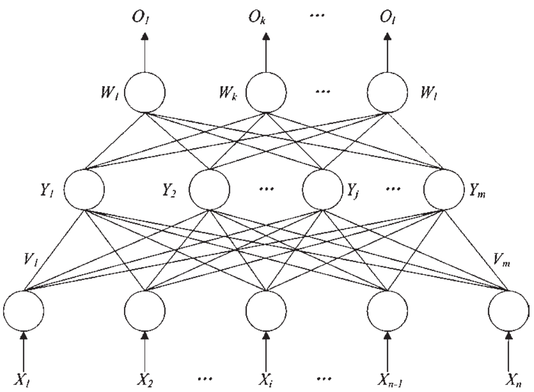

Figure 2 Three-layer BP network

The input vector is $X(X_1,X_2,...,X_i,...,X_n)$, the hidden layer output vector is $Y(Y_1,Y_2,...,Y_j,...,Y_m)$, and the output layer output vector is $O(O_1,O_2,...,O_k,...,O_l)$, the weight matrix between the input layer and the hidden layer is represented by V, $V(V_1,V_2,...,V_j,..., V_m)$, where V_j is the weight vector corresponding to the jth neuron in the hidden layer. The weight matrix between the hidden layer and the output layer is represented by W, $W(W_1,W_2,...,W_k,...,W_l)$, where W_k is the weight vector corresponding to the kth neuron in the output layer. In output layer, the output Y_j of the hidden layer is the sum of the products of all input vectors X_i and weights V_{ij}. In hidden layer, the output vector O_k is the sum of the products of all hidden layer output vectors Y_j and weights W_{jk}. The selection of hidden layer nodes has a great influence on the prediction accuracy of BP neural network, and the specific trial-and-error method is shown in Table 3.

Table 3 **Hidden node error table**

No.	5	6	7	8	9	10	11
Error	8	9,6	5	17	15	24	12

The results in Table 3 are the sum of the error values of samples 22 to 25 predicted by the neural network using different hidden layer nodes. According to the error in Table 3, the hidden layer node is selected as 7, so that the error is the smallest. Therefore, 4 input data matrices, 7 hidden layer nodes, and 1 output data matrix are taken into the software Matlab neural network toolbox, and the newff function is used to create a BP neural network as a prediction model. The hidden layer node transfer function of the network is selected. The logsig function, the output layer node transfer function uses purelin, and the weight training function uses the trainlm function, which uses the Levenberg-Marquardt optimization algorithm. The number of samples is predicted, and the prediction results are shown in Table 4.

Table 4 **BP neural networks prediction data table**

No.	22	23	24	25
Predicted output	47,4	48,5	50,6	50,5
Expected output	48,3	50,2	52	51,5
Error	0,9	1,7	1,4	1
Error percentage	1,86	3,39	2,69	1,94

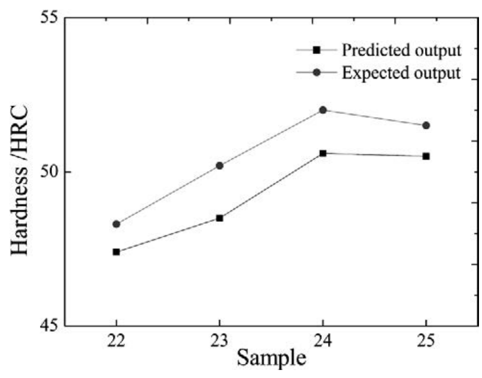

Figure 3 Predict contrast

The expected output in Table 4 is the actual measured value, and the predicted output is the predicted value of the BP neural network model. The sample 23 has the largest error of 1,7, and the error percentage is 3,39 %. The sample 22 has a minimum error of 0,9 and an error percentage of 1,86 %. This shows that the accuracy of the prediction model is high, and the trend of the predicted output and the expected output is also consistent, as shown in Figure 3.

GENETIC ALGORITHM OPTIMIZATION

The neural network model optimized by genetic algorithm mainly contains the training and fitting of neural network and genetic algorithm extreme value optimization. The algorithm flow is shown in Figure 4.

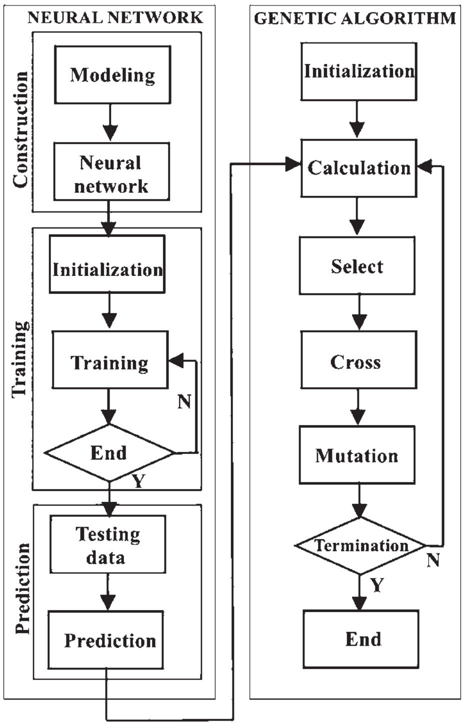

Figure 4 Optimization flow chart

The BP neural network created above is used to predict the hardness HRC of the laser quenching sample as the fitness value of the genetic algorithm. The range of process parameter variables is the current 200 – 230 A, the pulse width 0,8 - 1,4ms, the cutting speed 150 – 300 mm/min, the defocus amount -1 ~1mm. The genetic algorithm population is 50, that is, 50 are randomly selected as the initial optimization population within the range of these variables, which is the genetic algorithm selection operation. Then the optimal fitness value and corresponding variable value within the population range are found through the crossover operation with probability 0,4 and the mutation operation with probability 0,2. This iterative evolution process is 50 times, as shown in Figure 5.

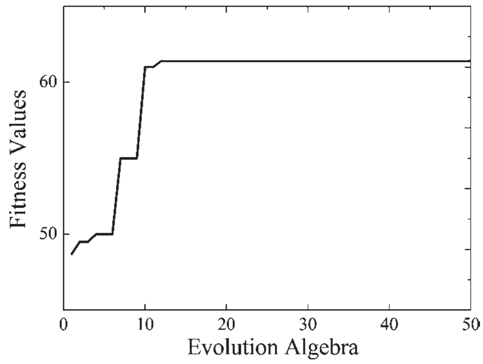

Figure 5 Fitness curve

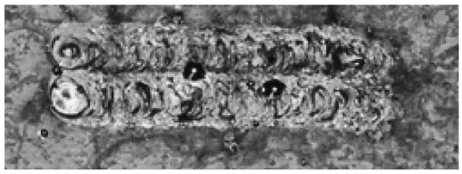

Figure 6 Confirmation experiment

According to Figure5, the optimal fitness value is 61,4. The corresponding variable is (226,1,29,161,0,2), that is, the current is 226 A, the pulse width is 1,29ms, the scanning speed is 161 mm·min-1, and the defocusing amount is 0,2 mm. The hardness of the confirmation experimental sample is HRC 60,8, indicating that the genetic algorithm has a certain reference value for optimization, figure 6.

CONCLUSIONS

The orthogonal experimental results show that laser quenching can significantly improve the surface hardness of 45 steel. The highest experimental sample is HRC 58, the theoretical hardness after optimization can reach HRC 61,4, and the actual hardness is 60,8. The neural network model optimized by genetic algorithm can realize the rapid optimization of laser quenching process parameters, and there are certain errors. The maximum error percentage is 3,39 %, which has some reference value.

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Note: The responsible translator for English language is Y.Y. Zhang, Huludao, China.