Study on Optimization of BP-GA Method Applied to Shaft Laser Cladding Repairing Technology

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Abstract. Laser cladding technique, which has the characteristics of refining microstructure, minimum deformation and high safety during processing, could enhance the strength of work-piece, shorten the repairing cycle and reduce the restoration cost by roughly sixty percent on shaft repairing. Process parameters optimization plays a key role in repairing quality and cost in laser cladding technique. This paper studied the application of YAG laser cladding technique on shaft repairing and which had important sense to popularize laser cladding technology. Through the experimental research and Artificial Neural Network-Genetic Algorithm approach, this technological process for laser cladding showed the capability to improve efficiency and quality of shaft repairing and reduce repairing cost with guarantee of enough bonding strength and no cracks in restoration area by optimization on key parameters like work-piece rotation speed, defocusing amount, powder stream rate.

1. Introduction

Normally, shaft parts has large ratio of shaft height and diameter, high rotate speed and high probability of damage. The common repairing solutions for shaft parts are welding repair, brush plating repair, ultrasonic welding repair and laser cladding repair etc. The normal welding repair would produce lots of heat during repair which cause parts deformation and could not be used for small parts repair. The brush plating repair use electrochemical techniques to coat metal layer on parts surface, which is not suitable for parts with deep crack or pitting and has the risk of environment pollution. Ultrasonic welding repair is suitable to repair those thin parts or plastic parts.

Laser cladding technology is a kind of new coating technology in modern industrial production, which use high energy Laser ray to melt powder that is placed in repair area, form molten pool and grind to size after cooling down to repair parts with parts surface modification [4]. Such technology has lot of technological characteristics like capability of melting kinds of alloy materials, ability to solve the problem of thermal stress and obvious thermal deformation occurred during normal welding operation, less impact to repair parts deformation, high safety and ability of machining parts with complex shape, hard to manufacture or with small processing surface.

The article studied laser cladding repair for a shaft with diameter at 60cm. Though experimental research, Artificial Neural Network-Genetic Algorithm approach, this technological process, it studied optimization on process parameters of YAG laser melting system, took defocusing amount, scanning speed and powder stream rate as study variables and hardness value of parts in repairing area as research target.
2. Experimental Research

2.1. Experimental Device
YAG Laser Cladding System consisted of YAG laser device, water cooler, cladding head, powder feeder, robot and auxiliary equipment, which could set and control process parameters like cladding speed, powder feed amount and defocusing amount precisely and was suitable to do surface repair or additive manufacturing for shaft parts or irregular workpieces. The leeb hardness tester with type of SW-6230 was used to measure hardness.

2.2. Experimental Materials
Test substrate was 35Cr and ground to smooth piece. The cladding powder was iron-base powder and main chemical composition of it is showed as sheet 1.

Table 1. Chemical Composition of Iron Base Alloy Powder

|   | Cr     | B       | Si       | Mn | Ni   | C     | Fe   |
|---|--------|---------|----------|----|------|-------|------|
|   | 16-18  | 0.50-0.80 | 0.75-0.90 | 0.35 | 1.5-2.0 | 0.20-0.22 | Bal  |

2.3. Evaluation of Repair Quality

2.3.1. Hardness Value. The document [3] tells that under some certain conditions, there is some certain conversion relationship between material hardness and material strength and material hardness could reflect material strength at such circumstances, which is why this article took material hardness as major research feature. The empirical relationship between HV, Vickers Hardness, and material tensile strength, which were acquired from experiments is as following.

\[ \sigma_b (MPa) = 3.602HV - 118.7 \]  

2.3.2. Bond Strength Test. The hardness value is not the only criterion to evaluate repair quality. The strength test and coloring test would also be needed. The bond strength test of this article was a lay of coating with thickness at 1mm by laser cladding with iron-base powder on one No. 35 steel workpiece. The chemical composition of iron-base powder is shows in Tab. 1. The results of such bond strength test was \( \sigma_L = 800 \text{MPa} \) and it told us that bond strength is enough.

2.3.3. Coloring Test. The coloring test should be done after laser cladding repair. The coloring test procedure of this article was repaired workpiece grinding, cleaning with detergent, penetrant spray, penetrant wipe off 5 min. later and photographic developer spray lastly. There was no voids and cracks in was found in repaired workpiece.

2.4. Test design and Results
There are lots of parameters concerned about YAG Laser Cladding process [1] like Light Source Parameters as laser power, distance from focus, pulse, beam profile, Processing parameters as accuracy, speed and acceleration, Powder material parameters as material composition, geometry, distribution, Parameters of powder feeding mechanism as nozzle, powder discharge rate, environmental parameters as type and flow of protective gas etc. From the perspective of process, taking equipment and control etc. into consideration, this article chose workpiece rotating speed \( n \), defocus amount \( H \) which was the height from protection lens of laser to workpiece, powder feeding speed \( C \) as independent variables. The test of this article was orthogonal experiment and the results is showed in Tab. 2.
Table 2. Orthogonal Experiment Results

| Num. of Test | A (n(r/min)) | B (H(cm)) | C (C(r/min)) | Test Results (Hardness (HRB)) |
|-------------|--------------|-----------|--------------|-------------------------------|
| 1           | 360          | 14        | 40           | 89.66                         |
| 2           | 360          | 14.5      | 45           | 88.90                         |
| 3           | 360          | 15        | 50           | 92.86                         |
| 4           | 400          | 14        | 45           | 87.50                         |
| 5           | 400          | 14.5      | 50           | 74.30                         |
| 6           | 400          | 15        | 40           | 91.26                         |
| 7           | 440          | 14        | 50           | 93.71                         |
| 8           | 440          | 14.5      | 40           | 89.40                         |
| 9           | 440          | 15        | 45           | 94.50                         |

| K1          | 271.42       | 270.87    | 270.32       | Sum of indicators of each factor |
| K2          | 253.06       | 252.60    | 270.9        |                               |
| K3          | 277.61       | 278.62    | 260.87       |                               |

| K1/3        | 90.47        | 90.29     | 90.11        | Avg. of indicators of each factor |
| K2/3        | 84.35        | 84.20     | 90.30        |                               |
| K3/3        | 92.54        | 92.87     | 86.96        |                               |

3. Analysis and Optimization of Data Variance

3.1. Visual Analysis
According to the data in Tab.2, the result of test of No.9 is the best. The horizontal combination of it is A3B3C3 which is defocus amount H=15cm, workpiece rotating speed n=440r/min and powder feed speed C=50r/min.

3.2. Range Analysis
After doing range analysis on data in Tab. 2, we could figure out the relationship of primary and secondary of Influence of processing parameters on hardness is defocus amount H > workpiece rotation speed n > powder feed speed C.

3.3. ANOVA
After doing ANOVA on data in Tab.2, we could find the best solution is A3B3C3, that is defocus amount H=15cm, workpiece rotation speed n=440r/min, powder feed speed C=45r/min.

4. Optimization Based on Neural Network Genetic Algorithm

4.1. Establish BP Neural Network Model
The BP three layer forward neural network model this article used is showed in Figure 2[2]. The input layer n is 3, which separately correspond to workpiece rotating speed, defocus amount and powder feed speed. Number of neurons in the hidden layer m is 12. Action function of hidden layer neuron is Symmetric S-function and output layer z is 1 and which correspond to hardness value of repair area.
4.2. Training and verification of BP
Except the Orthogonal test mentioned above, we also carried out 30 groups of single factor tests. Single factor tests were divided into two groups. Data in the first group was taken as training data and data in the second group was taken as validation data. After trained by LM training function, the result error between test value and predictive value of network model is less than 0.0555, which showed the network model had strong generalization and could be used for prediction and analysis.

4.3. Optimization on GA Research
In the scope of system parameters of laser cladding, taking the max. Output value of BP model as the target, we optimized three independent variables by Matlab GA toolbox. The hardness before and after variables optimization is showed in Tab. 3.

| Parameters and Results Before and After Optimization |
|-----------------------------------------------|
| Workpiece Rotating Speed(r/min) | Defocus Amount(cm) | Powder Feed Speed(r/min) | Predicted Hardness(HRB) | Test Results Hardness(HRB) |
| Optimized Parameters | 434 | 14.35 | 45.20 | 94.90 | 94.75 |
| Common Parameters | 400 | 14.50 | 45 | 91.26 | 91.90 |

5. Conclusion
Shaft is the main part of mechanical equipment and it is easy to get damaged. If we abandon the damaged one and rebuild a new one, the cost would be very high. This article studied application of shaft repair by laser cladding technology. Taking hardness improvement as target, with guarantee of enough bonding strength and no cracks in restoration area, this article studied the effects of defocus amount, workpiece rotation speed and powder feed rate on the repair and optimized accordingly and the results of study figure out the influence of processing parameters on hardness is defocus amount $H >$ workpiece rotation speed $n >$ powder feed speed $C$. The results optimized by BP neural network GA is defocus amount $H=14.35$cm, workpiece rotation speed $n=434$r/min and powder feed speed $C=45.20$r/min. The hardness value after optimized is 1.0326 times than that in common parameters. The bond strength test and coloring test also shows the repair quality by laser cladding is very good.

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