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Design of Laser Welding-Brazing Process Test and its Performance Test for Circuit Breaker Electrical Contacts

Xinlei Wei*, Shaoxing Su, Zhihui Zheng, Wuyu Song, Yanling Yu

School of Intelligent Manufacturing, Wenzhou Polytechnic, Wenzhou 325000, China

Abstract

According to the requirements of laser fusion brazing process and application index of circuit breaker electrical contacts, based on the previous research work and results, it is proposed to make use of the accurate controllability of high density laser energy, uniform diameter spot and action position and the difference of melting point of dissimilar alloys, which can provide ideas for efficient and high-quality connection of difficult-to-weld dissimilar materials.The details include the selection of test materials, the design of the test plan, the appearance inspection and ultrasonic non-destructive testing method, the shear-tensile strength test method of brazed joints, and the electrical performance testing method, so it is convenient to better analyze the action mechanism of laser welding-brazing and the regulation of microstructure evolution.

Keywords

Electrical Contact; Laser Welding and Brazing; Test Plan; Test Method; Mechanism of Action.

1. Introduction

At present, most of China's low-voltage electrical products have technical bottlenecks of unstable work, short service life and low load, so most of China's low-voltage electrical products are limited to the low-end market and have weak competitiveness.Poor contact welding quality, inability to load large current and frequent power on and off is one of the main reasons for the above problems. How to ensure the stability of contact welding quality in production has become a weak link in China's low-voltage electrical appliance industry, restricting the development of enterprises.Therefore, the core competitiveness of products could be improved by the constantly exploring new methods of welding contacts and improving the quality of contact welding.

Low-voltage circuit breaker takes its high reliability and long working life as the main quality index, and the welding quality of the contact directly determines whether the circuit breaker meets its performance index. The reason why the welding quality of the contact determines the quality of the electrical appliance is that the working environment of the contact is harsh. During the work, it is not only oxidized by the surrounding atmospheric environment, but also corroded by the evaporated corrosive gas, and the main and auxiliary contacts will generate a large number of high temperature and high speed plasma arcs during the contact and breaking process, and also these arcs will burn the surface of the contacts. The traditional brazing and diffusion welding methods of circuit breaker contacts generally require the overall heating of the connector, which has low efficiency, poor flexibility, and waste of energy. The size of the connector is limited by the heating equipment, and there are many limitations in application, specifically includes: 1) The uneven flow of the liquid solder results in uneven thickness of the brazing seam, which in turn leads to uneven mechanical and electrical properties in different areas of the joint; 2) The solder is generally composed of various alloys, and the high resistance of the solder itself , low thermal conductivity and low melting point, the brazing interface is easy to become a weak area; 3) Due to the incomplete metallurgical process

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of the brazing filler metal, the brazing seam is prone to defects such as bubbles and inclusions. Laser fusion brazing utilizes the difference in melting point of the two base metals to locally melt the low-melting base metal by laser heating, while the high-melting base metal basically remains solid, and the molten low-melting base metal infiltrates the interface of the high-melting base metal and undergoes a metallurgical reaction. In this way, the permanent connection of materials is realized, that is, fusion welding is performed on the side of the low-melting base metal, and brazing is performed on the side of the high-melting base metal.

This paper intends to carry out research on new laser welding-brazing process technology and welding mechanism of low-voltage circuit breaker electrical contacts. The goal is to develop a new type of laser welding and brazing circuit breaker contacts with high and stable welding quality. It is very clear and important to provide key enabling technical support for grade new products.

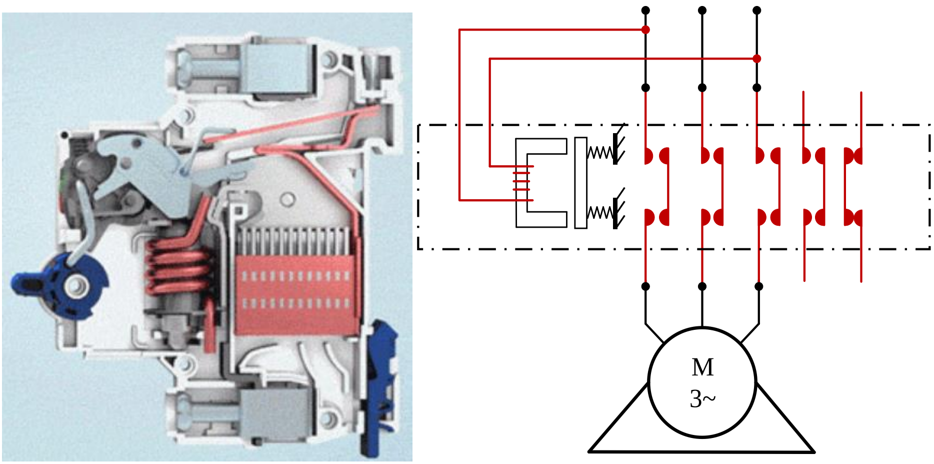

Fig.1 Schematic diagram of the structure and working principle of low-voltage circuit breakers

2. Test Material

The substrate material is T3 copper, the specific composition and properties are shown in Table 1, and it has the excellent electrical conductivity, thermal conductivity and ductility. The contact material is AgCdO made by internal oxidation method and sintering process, which has excellent electrical conductivity and thermal conductivity, good resistance to electric abrasion and electric welding resistance. The specific components and properties are shown in Table 2. Select the appropriate solder based on the physicochemical properties of the substrate material and the contact material. According to GB11364-2008 "Wetting Test Method for Brazing", the melting point of Ag30CuZn flux-cored silver solder is low, and it has good self-brazing effect and wettability, and the prepared brazing joint has high anti-corrosion effect, so Ag30CuZn is used as the brazing filler metal, and its specific composition and properties are shown in Table 3. FB102 silver brazing flux is suitable for rapid brazing copper and copper alloys, steel and stainless steel, cemented carbide, etc. with silver brazing filler metal in the temperature range of 550-900 °C. It can effectively dissolve the oxides on the metal surface faster and promote brazing. The flow distribution of the material makes the weld denser and stronger, and its composition (wt%) is: 35%B2O3, 42%KF, 23%KBF4.

Table 1. T3 Copper Composition and Properties

Name	Cu ($wt\%$)	Doping sum($wt\%$)	Conductivity IACS	Thermal conductivity ($W\cdot(m\cdot K)^{-1}\%$)	Resistivity $\mu\Omega\cdot cm$
T3	99.7	0.3	100.6	377	0.0171

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Table 2. Chemical composition and properties of AgCdO contacts

Chemical composition/%				Physical and mechanical properties			
Ag	CdO	Total amount of additives	Other total amount	Density $/(g\cdot cm^{-3})$	Resistivity $/(m\Omega\cdot cm)$	Brinell hardness $/HB$	Ag coating thickness $/mm$
87.7	10.5	≦1.5	≦1.5	9.98~10.30	2.30	650~1175	0.25

Table 3. Chemical composition and properties of Ag30CuZn solder

Name	Solidus temperature/℃	Liquidus temperature/℃	Brazing temperature/℃	Chemical composition/$wt\%$
Ag30CuZn	635~670	720~750	720~850	Ag:29~31 Cu:37~39 Zn:30~34

3. Test scheme

3.1 Pre-Welding and Post-Welding Treatment

The surface of the T3 copper-based samples are treated by the laser cleaning machine. The process parameters of the laser cleaning are the output power of 150W, the frequency of 80KHz, and the scanning speed of 3000mm/s, rapidly removed the oxide film, oil, impurities and moisture on the surface of the substrate. So as to ensure that there are no external interference factors in the welding process, such as stomata, poor fluidity of molten pool, insufficient metallurgical bonding and so on.

Considering that there may be slag scale, spatter, secondary oxide layer and unmelted residual structure in the metal weld formed by metallurgical reaction of Ag-Cu-Zn-Cd material system, the post-weld cleaning is performed by laser to ensure that the weld surface is clean , which is conducive to the observation and inspection of welding defects, and if the surface defects are found e, that can be liminated and repaired in time to ensure the quality.

3.2 Test Equipment and Fixture Design

Laser welding is characterized by large welding penetration, narrow welding bead, small heating affected zone and high energy density. laser welding also represents a fine balance between heating and cooling of materials in small intervals. The light-induced plasma in high power laser welding can shield the laser beam, and the plasma air mass formed above the welding pool absorbs the laser energy. it reduces the welding penetration, leads to the waste of laser energy, affects the stability of the welding process and reduces the welding quality, so it is very important to restrain and regulate the laser welding plasma effectively. Therefore, the primary work of this project is to optimize the structure of the laser welding joint, mainly to improve the laser light guide system, focusing system, coaxial nozzle, weld gas protection mechanism and other devices.

Fig.2 shows the structure principle of the dual focus composite laser welding head. By spatially splitting an incident laser beam, two focusing points on the front and rear of the workpiece surface are realized. The form of the line is more concentrated than the traditional line laser energy (the energy of the line laser is evenly distributed on the entire line, and the double focus is only concentrated at the two end points of the line), which is more in line with the high energy density

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required for welding, and does not increase the power consumption. Additional requirements for lasers. During the welding process, along the welding direction, the front focus is heated and melted, and the back focus further deepens the penetration on the basis of the front focus (when the energy is high enough to form a small hole welding effect), the existence time of the molten pool is prolonged, and the metallurgical reaction is sufficient. Thereby improving the weld quality.

Compared with the traditional single-focus beam welding, the split dual-focus distributes the same laser energy in a reasonable space, reduces the energy concentration in the single-focus case, and reduces the evaporation effect of the molten pool compared with the single-focus, thereby reducing the plasma It can effectively suppress the plasma shielding effect of laser welding, improve the efficiency of laser energy utilization, and increase the processing depth; and only by flexibly changing the relative distance between the focus points of the double beams, without changing the welding power and speed, it will not affect the welding depth and depth. The welding efficiency can control the volume and distribution of the plasma, which cannot be achieved with a single focus. The split-beam dual-focus laser processing head has a compact structure and is easy to disassemble and assemble. The incident light path and the adjustment light path are completely decoupled from the machine body, thereby reducing the installation requirements of the processing head on the machine tool.

For the contact material system of typical low voltage circuit breaker, such as silver graphite-copper, silver tungsten-copper, etc., it is very easy to react with nitrogen, hydrogen and oxygen in the air during welding, resulting in metallurgical defects such as pores, oxide slag inclusion, overburning and so on, in order to obtain a smooth and continuous surface without metallurgical defects, in addition to the position of beam focus, laser power, welding speed, shielding gas, material treatment and other factors. Welding fixture plays an important role in the control of weld quality. Therefore, a special welding fixture for alloy sheet welding with double-sided atmosphere protection is designed and manufactured, as shown in figure 3.

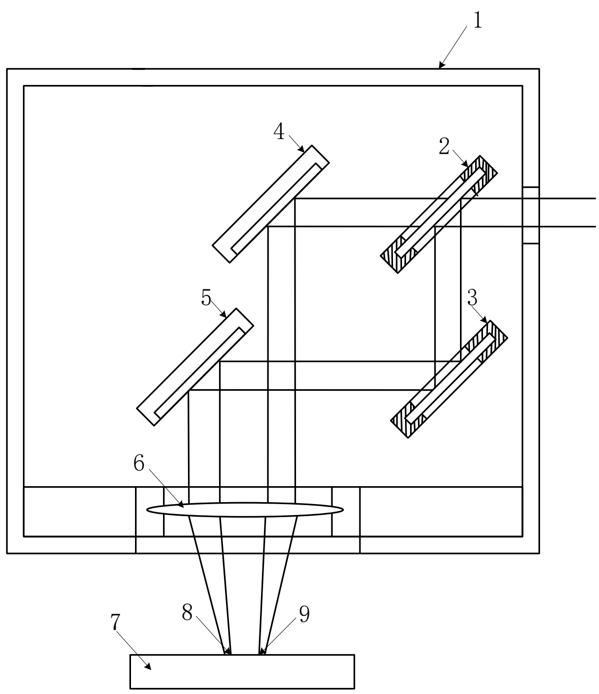

Fig. 2 Structure of dual focus composite laser welding processing head

The meanings of the symbols in the figure are: optical path cavity 1, beam splitter 2, first reflector 3, second reflector 4, third reflector 5, focusing mirror 6, workpiece 7, first spot 8, second spot 9

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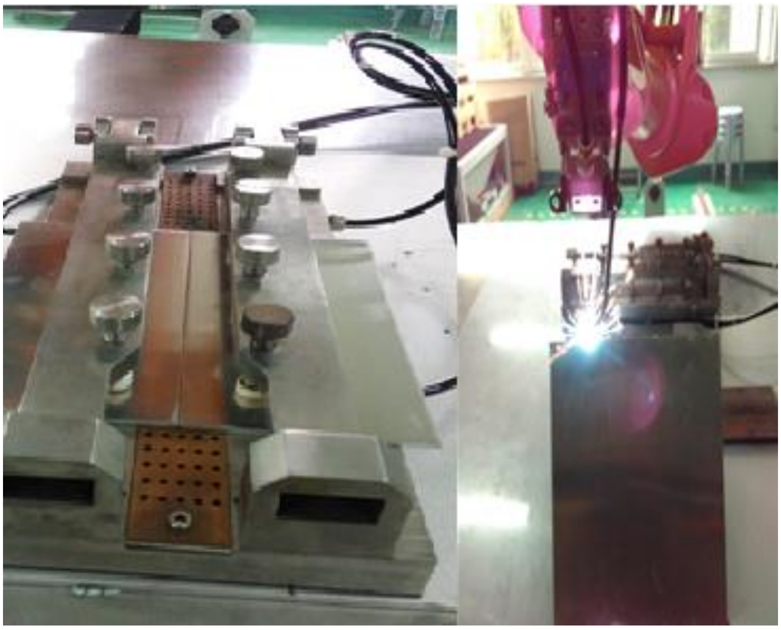

Fig. 3 Low-voltage circuit breaker contact alloy sheet laser welding fixture and welding site photo

3.3 Laser Fusion Brazing Process Parameters

The Wuhan Raycus 3000W fiber laser is plant to use in this experiment, the laser wavelength is 1060nm, the laser power is 800~1400W (continuous output), the welding speed is 500~900mm/min, the spot diameter <0.1mm, and with the precisely controlled laser welding heat input, the filled solder and flux alloys are melted, and the low melting point copper-based alloy contact bridge side of the electrical contacts is partially melted, while the high melting point contact side is passed through the molten copper The base alloy, filler brazing material and flux are used for brazing connection. The specific laser fusion brazing process parameters are shown in Table 4.

Table 4. The process parameters of laser welding-brazing

Factor	Laser output power P/W	Scan rate V/mm·min^{-1}	Positive defocus amount mm	Overlap rate %
1	800	500~900	-3~3	40
2	900	500~900	-3~3	40
3	1000	500~900	-3~3	40
4	1200	500~900	-3~3	40
5	1300	500~900	-3~3	40
6	1400	500~900	-3~3	40

4. Appearance Inspection and Ultrasonic Nondestructive Testing Methods

Combining the appearance inspection and ultrasonic non-destructive testing to evaluate the macroscopic morphology and internal defects of the above samples: 1) It mainly detects whether the brazing angle of the electrical contact is full after welding, and whether there is incomplete or overflowing of the brazing filler metal; 2) The non-destructive testing mainly uses the JTUIS automatic ultrasonic non-destructive testing equipment to detect the overall brazing rate of the electrical contacts. Due to the difference in the combination of test process parameters, some samples have incomplete spreading of solder and flux during processing, poor metallurgical bonding effect or overflow caused by excessive filler, etc., which affect the soldering rate of electrical contacts, and the appearance not to standard.

5. Test Method for Shear and Tensile Strength of Brazed Joints

The mechanical properties of the brazed joints are characterized by shearing and tensile tests, and the laser fusion brazing samples under different process parameters are subjected to shearing tests using a universal testing machine to obtain the average shear strength of multiple groups of brazed joints JM1~6, and determine the highest value JHK, and draw the load-displacement curve through the data analysis software, which is helpful to find out the key factors that cause the serious decline of the weld strength: 1) the starting point of the crack of the brazing structure; 2) a large number of continuously distributed brittleness Crack propagation paths for intermetallic compounds.

The fracture surface after shear test is observed by metallographic microscope and SEM, the fracture morphology of the fracture brazed joint is obtained, the dimple characteristics of shear and tension are analyzed, and the toughness, plasticity and shear resistance of brazed joint are further explained. Combined with the fracture morphology showing the characteristics of intergranular dimple and cleavage fracture, the shear fracture mode of joint is judged as follows: 1) ductile fracture mode; 2) brittle fracture mode. 3) compound fracture mode with ductile and brittle characteristics.

6. Electrical Performance Test Method

Electrical performance is the key factor affecting the reliability and stability of the circuit breaker: 1) When the current passes through the contacts, the exothermic effect caused by the resistance value will cause the temperature rise effect of the brazed joint structure; 2) When the switch is turned off , a brief arcing effect can ablate the electrical contacts. Therefore, it is necessary to comprehensively test the temperature rise, breaking, and electrical life of the high-quality laser welding and brazing electrical contact samples obtained under different process parameters, and to observe the microscopic morphology of the microstructure by the SEM after arc erosion.The specific test scheme is as follows:

1) Conduct on-off capability test on the post-weld sample, set the test voltage to 240V, the test current to 12.8A, the frequency to be 30 times/min, the power factor to be 0.35, and to observe the macroscopic surface of the dynamic and static contacts of the sample after 220 on-off times. And carry on the microscopic analysis to the cross section of the welding tissue.

2) Conduct an electrical life test on the post-weld sample, set the test voltage to 250V, the test current to 11.5A, the frequency to be 40 times/min, the power factor to be 0.5, and to observe the electrical contacts of the sample undergoing arc ablation after 40,000 on-off times. Micro and macro morphology of the organization, especially the causes and characteristics of pores, cracks and quenched segregators that may be generated in the ablation zone.

7. Conclusion

In this paper, the welding process test and test scheme design of electric contact of circuit breaker are carried out based on laser fusion brazing technology. it is described in detail from many aspects, such as test material selection, test scheme design, appearance inspection and ultrasonic nondestructive testing method, brazing joint shear-tensile strength test method, electrical performance test method and so on. The physical and chemical properties of the test materials and the metallurgical bonding effect under the condition of laser thermal action are explained emphatically. for the design content of the test scheme, the design and working principle of the self-developed dual-focus hybrid laser welding processing head and special welding fixture are put forward, and the detailed laser fusion brazing process parameters are given. At the same time, it also provides detailed test indexes and methods for pre-and post-welding treatment and macro-microstructure performance test and analysis, in order to provide systematic reference ideas for readers in related fields.

Acknowledgments

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