Analysis of different welding speeds and the micro structure on the welded joints of silicon steel pipe

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Abstract. This research “the analysis of different welding speeds, the micro structure on the welded joints of silicon steel pipe” has been carried out on precise and accurate measurements of parameters. The effects of different laser powers on the weld material have critically been studied and analyzed. Welding speeds have great effect on the micro-structure and morphology of the weld material. The determination of the basic components of the active agent is the key of the preparation. The active materials selected in this experiment are the commonly used oxides (SiO₂, TiO₂, and Cr₂O₃) and fluoride (NaF) reagents. However, the comprehensive experiment contains a large number of the level of combination; the workload is huge, due to the experimental site, experimental materials, funding, and time constraints lead to low efficiency. In the laser welding of silicon steel sheet, coating active agent can increase the penetration depth and affect the weld formation, and the influence of active agent NaF and SiO₂ on weld penetration of silicon steel sheet is significant. The formula G is the most effective in increasing the penetration depth, including 25% SiO₂, 25% TiO₂, 12.5%Cr₂O₃ and 37.5% NaF.

1. Introduction
In this research, 16 groups of mixed active agents composed of SiO₂, TiO₂, Cr₂O₃ and NaF were coated on the silicon steel sheet substrate with the thickness of 0.05 mm, and laser welding was carried out. The welding power was 500 W and the speed was 0.03 m / S, in order to increase the weld penetration of silicon steel sheet. Specific contents include:

- Details of the composition and working principle of the laser equipment used in the experiment; the processing conditions and the shape and size of the material; the micro hardness and other test methods.
- The formula of orthogonal experiment was used to study the effect of active agent on the forming and surface penetration of silicon steel sheet.
- The micro-structures and mechanical properties (tensile strength, hardness, etc.) of the welded joints with and without the active agent were observed and tested [1]. The effects of the active agents on the micro structure and properties of the welded joints were compared.

Demands for silicon composite materials are becoming increasingly higher because of their promising use and application in nanotechnology [2]. Bulk silicon materials are nowadays major raw materials for alloy industries especially in the manufacture of steels for use in hard materials such as rail lines, steel pipes etc. The study of the physical properties, characteristic shape, tensile train and micro structure is therefore very important. Most metallurgical firms apply laser welding to join metals, therefore an
investigation is needed on the most suitable method to be adopted, the suitable welding speed, welding power range, and the ability of the active agent to improve the quality of the weld. A lot of researches have been conducted on the study of weld morphology of silicon steel, the investigation shows that silicon weld can be improved by the addition of active coating agents such as CrO3.

2. Research methods
In this experiment IPG3000W fiber cross flows in a continuous wave laser of 0.05mm silicon surface by laser welding, by changing the four different experimental conditions: welding speed of 0.03m / s, through the defocus amount of 0 mm, at the angle of 7°, laser the power of 300 W, 350 W, 400 W, 450 W, 500 W, 550 were used respectively; when the laser power is 500W, the defocus amount is 0 mm, the control speeds are 0.01 m / s, 0.02 m / s, 0.03 m / s, 0.04 m / s, 0.05 m / s, 0.06 m / s, 0.07 m / s, 0.08 m / s; for the laser power of 500 W and speed of 0.03 m / s, the control of the defocus amount respectively is +2 mm, -2 mm; laser power of 500 W, when the defocus amount is 0 mm, coated with an active agent are Cr2O3, TiO2, SiO2, at the same time in order to prevent oxidation of the welding material, we use argon as a protective gas [3].

3. Effects of welding speed on the weld
Figure 1 shows a laser power of 500 W, the welding speed of 0.02 m / s, 0.03 m / s, 0.04 m / s, 0.05 m / s were applied to the weld profile. It can be seen from the figure that the welding speed increases with the laser power. This result leads to the increase in the weld aspect ratio hence the heat affected zone (HAZ) is narrowed making the weld surface smoother.

![Figure 1. Ferrite fractions under different laser powers](image)

The morphologies of the welding joints can be seen in Figure 2 with different microstructures, it can be seen that the morphology varies with different welding speeds, the weld penetration is narrower at 0.05 m/s and is coarser at 0.01 m/s. it is therefore clear that active agent is the key factor to improve the quality of laser welding.
Figure 2. Weld topography under different speeds at magnification of 200 μm

4. Micro hardness analysis of welded joints

Hardness is an extremely important mechanical performance indicator which reflects the plastic deformation properties of the material. There is a relationship between hardness and strength [4]; we can estimate the approximate intensity values according to the hardness value. Chemical composition and microstructure of the material hardness depends on the hardness of the material. It is an important basis for the mechanical properties; it is often used to determine the relative hardness of the metal structure composed by weld hardness and can generally assess welding mechanical properties of the sample. Hardness depends on the chemical composition and microstructure of materials [5].

Figure 3 is a micro hardness of laser welded joints under different power distribution, the horizontal axis represents the distance, and the vertical axis represents the value of the hardness measured from the left point to the horizontal right side of the base substrate. As can be seen from the figure, the hardness values were normal with weld up to the maximum hardness value, and from both sides of the weld the hardness value is decreasing, it is clear that weld hardness value is much larger than the base region material hardness value.

Further, as the laser power increases the hardness value decreases. This is because, with reduced laser power, the laser output energy is reduced, the heat absorption pipes is reduced, the temperature gradient is reduced, the cooling speed, so there is no sufficient time to grow grains, and therefore grain refinement [6]. At this time, due to the fine grain strengthening the role of action at this time coupled with more intense solid-solution strengthening, aging strengthening and phase transformation strengthening effect, increased strength, hardness increases.
It can be seen from Figure 3 that the micro hardness drastically reduced to zero for the laser power of 500 W. This is because as the welding speed increased, the heat affected zone (HAZ) becomes very soft to the level of forming a pool of molten liquid weld material. The hardness is maximum at 0.58 mm and minimum at -0.58 mm [7].

4.1 Discussion
In this experiment IPG3000W fiber cross flows in a continuous wave laser of 0.05mm silicon surface by laser welding, by changing the four different experimental conditions: welding speed of 0.03m / s, the defocus amount is 0 mm, when the angle is 7°, laser the power was 300 W, 350 W, 400 W, 450 W, 500 W, 550 respectively; when the laser power is 500W, the defocus amount is 0 mm, the control speeds are 0.01 m / s, 0.02 m / s, 0.03 m / s, 0.04 m / s, 0.05 m / s, 0.06 m / s, 0.07 m / s, 0.08 m / s; for the laser power of 500 W and speed of 0.03 m / s, the control of the defocus amount respectively is +2 mm , -2 mm; laser power of 500 W, when the defocus amount is 0 mm, coated with an active agent are Cr₂O₃, TiO₂, SiO₂, at the same time in order to prevent oxidation of the welding material, we use argon as a protective gas.

5. Multi-component compound active agent formulations and activity - laser welding
According to the design principle of orthogonal experiment, 16 sets of multicomponent active welding experiments were carried out on the active-laser welding experiment system of YLS-3000W fiber cross-flow continuous wave laser.

5.1 Sample analysis
In the experiment, when the silicon steel sheet of the motor was cut, the coolant was deposited on the surface of the silicon steel sheet by the electric spark, or the silicon steel sheet was oxidized in the air for a long time, the surface of the substrate would form an oxide film, and oxide film affect the quality of welded joints, so the oxide film and oil must be handled before welding. With fine sand paper grinding specimen, remove the surface of the oxide layer; with acetone cleaning the surface of the oil test, and then scrubbed with alcohol; Or dry with a hair dryer. Then the alcohol and SiO₂, TiO₂, Cr₂O₃, NaF four kinds of active agent powder into a paste, with a flat brush to the different components of the active agent evenly coated on the specimen, so that all parts of the coating will maintain essentially the same thickness. There is no protective gas in the welding process.
**Table 1.** Multi-component active agent formula orthogonal

| Active Agent | SiO₂(g) | TiO₂(g) | Cr₂O₃(g) | NaF (g) |
|--------------|---------|---------|----------|---------|
| A            | 0       | 0       | 0        | 0       |
| B            | 1       | 1       | 1        | 1       |
| C            | 1       | 2       | 2        | 2       |
| D            | 1       | 3       | 3        | 3       |
| E            | 1       | 4       | 4        | 4       |
| F            | 2       | 1       | 2        | 4       |
| G            | 2       | 2       | 1        | 3       |
| H            | 2       | 3       | 4        | 2       |
| I            | 2       | 4       | 3        | 1       |
| J            | 3       | 1       | 3        | 2       |
| K            | 3       | 2       | 4        | 1       |
| L            | 3       | 3       | 1        | 4       |
| M            | 3       | 4       | 2        | 3       |
| N            | 4       | 1       | 4        | 3       |
| O            | 4       | 2       | 3        | 4       |
| P            | 4       | 3       | 2        | 1       |
| Q            | 4       | 4       | 1        | 2       |

Table 2 shows the different speeds of the weld width, penetration and aspect ratio size, the rate of penetration achieved was maximum at 0.07m/s.

**Table 2.** Different speeds weld width and depth

| Speed (m/s) | Width W(μm) | Depth H (μm) | Ratio |
|-------------|--------------|--------------|-------|
| 0.01        | 1754.6522    | 515.2652     | 0.294 |
| 0.02        | 467.8783     | 173.0979     | 0.370 |
| 0.03        | 861.2692     | 467.7154     | 0.543 |
| 0.04        | 568.4697     | 411.4210     | 0.724 |
| 0.05        | 593.1681     | 482.8517     | 0.814 |
| 0.06        | 564.6388     | 526.7395     | 0.933 |
| 0.07        | 714.8314     | 716.0936     | 1.002 |
| 0.08        | 456.2896     | 555.2503     | 1.217 |

Figure 4 is for the speed on the weld depth to width ratio. As it can be seen with increasing aspect ratio the welding speed increases [12-13].
6. Recommendation

In order to obtain the compound with good penetration effect, it is necessary to find out the optimum proportioning scheme of the single component in multi-component compound active agent by experiment. However, the comprehensive experiment contains a large number of the level of combination; the workload is huge, due to the experimental site, experimental materials, funding, time constraints lead to low efficiency. Therefore, it is an important step to decide whether or not this experiment is successful because it is a quick and efficient way to improve the efficiency and efficiency of the experiment. Taking into account the main purpose of this experiment is to seek the best combination of a variety of single components that can be used orthogonal design to arrange the experiment.

A complete and reasonable experimental process should contain the design optimization experiment and analysis of experimental results of two links [8]. The experimental design is the basis of the experimental process, is the prerequisite for experimental data processing, but also improve the quality of scientific research is important. Orthogonal experimental design can solve the above two problems, it uses a set of standardized orthogonal table scientifically arranged experiments, the experimental results and then the mathematical statistical methods to deal with. The main advantage is that a large number of experimental programs can be selected representative of a small number of experimental programs, by a small number of experimental results for further analysis of experimental results can be obtained more than the experimental results of the factors of their own information. Orthogonal experiment design has become an important aspect of modern optimization technology because of the rational design of experimental scheme, effective control of experimental interference, scientific processing of experimental data [9,10,11].

In this experiment, according to the literature selected single component experiments can increase the penetration effect of SiO₂, TiO₂, Cr₂O₃, NaF four oxide composition as the orthogonal test of the four factors, select the four factors and four levels Orthogonal experimental table to complete the design of orthogonal experiments, orthogonal table as shown in 2.1. Set the four levels of 1 g, 2 g, 3 g and 4 g, with an electronic balance in accordance with the quality requirements of each group of experiments accurately weighed, will weighed each group of mixed active agent mixing evenly with anhydrous Alcohol in accordance with the ratio of 1: 1 to reconcile into paste paste spare, and then the active agent evenly coated on the surface of the weld to be thin layer (0.3 mm or so), coating width of 5 mm or so.
7. Conclusions
YLS-3000W fiber cross-flow continuous wave laser was used to study the active-laser welding process with the silicon steel sheet of 0.5 mm thick motor as the base material. Through the multi-component active agent orthogonal laser welding test, the ratio of weld depth to width, and the microstructure of the weld were studied. The optimum formulation of the active agent was obtained through the use of modern testing equipment and technology to optimize the formulation of the active agent under the weld zone and heat affected zone of the sample, performance, comprehensive analysis. In the laser welding of silicon steel sheet, coating active agent can increase the penetration depth and affect the weld formation, and the influence of active agent NaF and SiO2 on weld penetration of silicon steel sheet is significant. The formula G is the most effective in increasing the penetration depth, including 25% SiO2, 25% TiO2, 12.5% Cr2O3 and 37.5% NaF.

The use of YSL3000W laser machine greatly improves the Quality of the weld through hardening of the weld joint. This is achieved by small addition of active agents which are mainly oxides such as 25% SiO2, 25% TiO2, 12.5% Cr2O3 and 37.5% NaF. Welding speed increases linearly with the power of the weld, the heat affected is narrowed by the continuous increase in the weld power and the weld speed. This experiment understands that coating the weld surface with active agent increase the weld penetration by about 0.02 cm, it also affect the weld formation and influence the weld to depth ratio.

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