Research on Strengthening Process of Laser Additive Remanufacturing of Mill Housing

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Abstract: Based on the analysis of the wear mechanism of the mill housing, the results show that the main failure forms of the mill housing are corrosion wear and stress wear. Therefore, it is proposed to remanufacture and repair the housing to improve the hardness and impact resistance of the wear part of the housing. In order to strengthen the wear resistance of the wear part of the housing, Fe₄₅+5%WC alloy powder was prepared to strengthen the wear resistance of the worn part of the housing. The sample of the alloy layer was produced by high power semi-conductor laser, the hardness, impact toughness and surface PT were tested, and the microstructure was observed by metallographic and EDS experiments. The results show that the alloy layer has high hardness and wear resistance, and the grains are fine and the alloy layer is metallurgical bonded to the substrate. The 3500mm reversing mill housing was repaired by laser re-manufacturing technology, and it was found that the alloy layer had good bonding and surface hardness was improved, thus strengthening the housing.

1. Introduction:
The output and quality level of iron and steel reflects the strength of a country's iron and steel industry and is also an important indicator of the country's basic industry, the surface quality and high performance of rolled steel sheet are indispensable raw materials for automobile, household appliances, construction, electric power, ship and other industries. In this paper, a 3500mm reversing rolling mill in an iron and steel enterprise is taken as the research object. The equipment of this mill has been used for 7 years and has been idle for many years, so there are different degrees of wear and rust in various parts. The mill housing is an important part of rolling machinery. The rolls, housing rolls, roll cooling and descaling guides and other devices are all installed on the housing. The housing bears huge rolling force during rolling, and because the working environment has been in high temperature and high humidity environment, easy to cause serious surface corrosion to the whole rack [1-2]. The research on the wear failure mechanism of the mill housing and the development of the housing repair process have become an important issue in the steel industry.

Laser additive remanufacturing uses a laser to concentrate a high-density heat source to cause a local metallurgical reaction between high-performance alloy powder and the surface of the metal substrate, prepares an alloy layer with excellent properties such as high temperature resistance, abrasion resistance, and impact resistance on the surface of the substrate, repairs the size of the part, and realizes the remanufacturing of the product. At present, the commonly used alloy powder
materials mainly include iron-based, nickel-based, cobalt-based and metal-based ceramic powder materials, the Fe-based alloy powder has the advantages of good wettability and adhesion, low dilution rate and little effect of metal substrate on the properties of alloy layer, so it is suitable for the components with heat resistance, corrosion resistance and wear resistance [3-5].

In this paper, the laser additive remanufacturing technology is applied to the repair of the mill housing. Through the investigation of the wear mechanism of the housing, the experiment of laser additive remanufacturing of the samples with iron-based alloy powder is carried out, the hardness, impact and wear of the substrate and the repaired specimens were compared.

2. Analysis of wear mechanism

2.1 Current status and repair location

The annual design output of the 3500mm reversible rolling mill before the shutdown was 600,000 tons, and the maximum annual output was close to 1 million tons. During the production process, its overall operation was relatively stable, but repeated failures occurred in individual parts. The entire rolling mill production line has severe corrosion, especially during the production process of the lower work roll compaction cylinder, the important gripping surface has suffered multiple wear and tear. Therefore, various repair methods such as on-site repair welding and backing plates have been carried out.

The housing adopts a closed integral cast steel structure, with a unit weight of about 300 tons, and its length, width and thickness are about 13,300×4750×2000mm.

(1) Housing window

The large rolling force during work and the long idle time of the equipment, the sliding plate position of the rolling mill housing window has been rusted and deformed. Therefore, key inspections need to be performed to determine the repair amount of the housing window. Corrosion and fatigue hardened layer should be removed by processing the housing window corresponding to the lower support roller.

(2) Positioning surface of lower work roll

The position of the press cylinder of the work roll under the installation of the mill housing has caused the axial movement of the work roll during the rolling process due to the wear and deformation
of the housing body, the Intermediate Repair in 2008 was solved by hand grinding the worn position of the rack and adding a gasket (10-12.6 mm). This time, it is necessary to add spacers after strengthening the positioning surface.

(3) Mounting surface of housing roller

The housing rolls, cooling and descaling guide and guard device and side blowing water of the mill need to be redesigned, and the corresponding fixed position on the housing (the most important mounting surface of the housing roll) need to be strengthened.

![Figure 2 Worn window surface and mounting surface](image-url)

2.2 Wear failure analysis

The mill housing is constantly impacted by forces in all directions during its operation. For example, the rack rolls mainly involve water cooling systems such as phosphorus removal cooling before and after the work rolls, the liner itself, and the mating surface of the liner and the archway will produce normal metal fatigue wear.

The rolling mill works under severe working conditions of high temperature and high humidity, even if the surface finish and flatness of the mating surface between the liner and the housing is very high, it cannot achieve a 100% fit. During the working process, the cooling water is atomized by heating steel billet, mixed with iron oxide powder on the billet surface, and enters the gap between the mating surface of the liner and the mill housing, which will cause different degrees of corrosion and wear on the inner window surface of the mill housing and the bottom surface of the housing. In particular, the phosphorus removal and the related cooling water are collected through the lower part of the arch, and the lower backing plate is located in the pit, the environment is even worse, the lower backing plate is mainly corrosive wear. The corrosion of cooling water to the mill housing is one of the most important reasons for the corrosion and wear of the mill housing.

In the long rolling process, the oxide layer and the lining plate continue to be squeezed and slapped, further increasing the gap, leading to metal fatigue on the surface of the housing in a short time, and then causing the wear of the housing. The gap between the housing and the lining plate increases the vibration impact of the main drive, and it is easy to slip when the steel nails bite, even affects the quality of the rolled products. The lower work roll pressing cylinder is mainly installed with a pressing cylinder to prevent the uneven rolling force of the lower work roll during the rolling process from causing the work roll jump to affect the wave shape of the slab, and this part of the stress and wear is serious.

In summary, it can be seen that the main wear of the housing is corrosion wear and stress wear. Therefore, in order to improve the wear resistance of the housing, it is necessary to ensure that the mating surface of the housing has sufficient hardness and toughness.

3. Experiment methods

3.1 Preparation of test pieces

The Matrix material used in this experiment is No. 25 Steel Plate, which is similar to the steel ZG230-450 used for repairing machine housing. No. 25 steel is a kind of high quality carbon structural
steel with certain strength, hardness, plasticity and toughness. According to the requirements of high surface hardness and high wear resistance of the housing, the alloy powder material is Fe45+5%WC composite powder. Among them, Fe45 has good wear resistance, impact resistance and wetting properties, and WC has high hardness, wear resistance and oxidation resistance. Using WC as the hard phase and Fe45 as the bonding phase, the alloy layer was fabricated by laser re-manufacturing with high hardness, good wear resistance and excellent impact resistance.

| Table 1 Chemical composition of Fe45 powder (mass fraction, %) |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| C               | Cr              | Si              | Ni              | B               | Fe              |
| 0.6             | 7.5             | 2               | 22              | 3               | Margin          |

In this experiment, FL-DLight-4000 high-power semi-conductor laser is used as the heat source, and is carried on the 5-dof industrial manipulator to realize the accurate control of the alloy layer. Clean the No. 25 steel substrate with alcohol and housing by Fe45 + 5% WC alloy powder was placed in the mechanical mixer and stirred for 3 hours. After being taken out, the coincidence powder was heated to 120°C in the oven and kept warm for 2 hours to remove the moisture from the coincidence powder. The mixed powder after heat preservation is added into the powder feeder, and under the protection of Inert Gas Argon, the alloy powder is uniformly fed into the molten pool by means of side feed.

| Table 2 Process parameters of laser additive remanufacturing |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Power (kw)      | Scan speed (mm/min) | Overlap rate | Spot size (mm*mm) | Powder feeding speed (g/min) |
| 3000            | 450             | 25%            | 14*2            | 120             |

As can be seen from Fig.3, the surface of the alloy layer obtained by laser additive remanufacturing technology is smooth and smooth, and the composite powder has good wettability. Fig. 4 the surface of the remanufactured specimen is stained and penetrant inspection (PT). It can be seen that there are no pores and cracks on the surface of the composite layer, and the surface quality is good.

3.2 Hardness test
Hardness reflects the ability of metal materials to resist external pressure. It is generally believed that the higher the hardness of the material, the better the wear resistance, so the hardness value of the material has become one of the important indicators to measure the wear resistance of the material. In this experiment, Ha-150a Rockwell hardness tester was used to measure the surface of the alloy layer at different positions.
3.3 Impact toughness test
Impact toughness is an important index to evaluate the toughness of metal materials, which reflects the ability of metal materials to resist the impact of dynamic load. According to the national standard GB/T 229-1994 Metal Charpy Notch Impact Test, the test piece with the specified size is placed on the simply supported beam support, and the pendulum is dropped from the specified height for a one-time blow to measure the impact absorption energy consumed by the test piece. The experiment adopts the JBS-300 pendulum impact test machine to enter the pendulum impact test. The maximum impact energy is 150J, the pre-lift angle of the pendulum is 150°, and the impact velocity is 5.2m/s.

3.4 Metallographic test
The metallographic structure reflects the specific form of the metallographic structure and is one of the important methods for analyzing the structure of materials. The preparation process of metallographic samples generally includes sampling, rough grinding, fine grinding, polishing and corrosion.

The metallographic block sample, the size of which is about 20mm*20mm*20mm, can be made by wire cutting, a grinding surface is selected and determined, the sample is polished by sand paper from coarse to fine, after polishing, the sample is washed and dried by water, otherwise, it will rust. The microstructure of the corroded sample was observed and analyzed under XJP-300 metallographic microscope.

4. Experimental results and analysis

4.1 Hardness test results and analysis
The hardness test shows that the surface hardness of the alloy layer meets the wear requirements of the housing, and the WC has not been decomposed by the laser thermal radiation on the embedded Fe-based solid solution, which acts as a strengthening phase to reduce wear. The average value is shown in Table 3.

| Hardness distribution of alloy layer (HRC) | Average value |
|------------------------------------------|----------------|
| 43.5                                     | 44             |
| 42                                       | 43             |
| 43                                       | 43             |

4.2 Impact toughness test results and analysis
The impact toughness value is the impact absorption energy consumed per unit cross-sectional area of the test piece with notches, expressed by the symbol $\alpha_k$, and the calculation formula is:

$$\alpha_k = \frac{A_k}{S}$$  \hspace{1cm} (1)

$\alpha_k$ is the impact toughness (J/cm$^2$);
$A_k$ is the impact absorption energy (J);
$S$ is the cross-sectional area of the sample notch (cm$^2$).
Table 4 Impact test data

| No. | Impact absorption power (J) | Fracture surface area S (cm²) | Impact toughness αk (J/cm²) | Average value (J/cm²) |
|-----|---------------------------|-------------------------------|-----------------------------|-----------------------|
| 1#  | 72                        | 0.80                          | 90                          | 90.8                  |
| 2#  | 73                        | 0.80                          | 91.25                       |                       |
| 3#  | 73                        | 0.80                          | 91.25                       |                       |

Through the above experiments, it can be found that after the laser additive remanufacturing and repair of the surface of No. 25 steel, the impact toughness of the specimen with the alloy layer does not change much. Under the premise of increasing the hardness of the composite layer, it still has excellent impact toughness.

4.3 Metallographic analysis

The microstructure of the alloy layer was found to be columnar or polygonal block carbide. The content of Cr in the alloy powder is high, and carbides are easily formed in the matrix solid solution. The WC hard phase is dispersed on the alloy surface to form a reinforced surface with high hardness and wear resistance. After the repair, the alloy layer is metallurgically bonded to the Matrix and has uniform microstructure, which makes the alloy layer have excellent impact resistance.

4.4 Binding zone detection

After scanning by SEM, the laser remanufacturing strengthened alloy layer after corrosion was metallurgically bonded to the No. 25 steel matrix, and the bonding property was good, and no macrocosm and microcosm defects such as cracks and pores were found, it can be seen that the microstructure and grain of the alloy layer are finer. As the laser additive remanufacturing process is a fast cooling and fast heating process, the temperature gradient is very large, so the grain size is very small, the microstructure and properties are excellent, and the comprehensive properties of remanufactured products are improved.
5. Laser additive remanufacturing strengthened housing

5.1 Housing repair process
This remanufacturing of the reinforced housing is for the restoration of the old. There are more uncertainties in the housing restoration process. The repair process is improved as follows:

1. Preparation before restoration
Before laser additive remanufacturing, check the machining volume of the housing on the spot, inspect the machined surface, and propose to clean up the defects such as pores and trachoma on the surface before repairing welding and polishing;

2. Surface cleaning
Since the poor working conditions of the housing and the long-term suspension of production and idleness, a large amount of rust, oil and other dirt are attached to each part of the rolling mill housing. After cleaning up quickly, use a cleaning agent to remove the oil and other dirt;

3. Log data reasonably to remove the fatigue layer
Because of the influence of the wear surface and the housing window on the neutrality, the housing size is not uniform wear, so we should record the key size data, reasonably remove the thickness of the fatigue layer, and determine the repair size of each machining surface, determine the amount of repair for each dimension separately.

4. Equipment and process debugging
Before repair, the equipment such as laser and manipulator should be debugged in order to be normal, and the process of adjusting the equipment parameters such as laser power, powder feeding rate, scanning speed and protective air pressure should be adjusted on the experimental board under the simulated repair condition, ensure that the alloy layer thickness, surface smoothness, repair quality is uniform.

5. Repair according to the processing sequence
According to the usage and user requirements, the 3500 rack requires a total of three repair positions, including the following three: the liner on both sides of the lower support roller, the installation position of the rack roller, and the position of the lower work roller pressing cylinder.

![Figure 9 Laser Additive Remanufacturing and Repair Process of Mill Housing](image)

5.2 Main points of laser additive remanufacturing rack process
(1) The laser repair adopts the way of side feeding powder, the sudden high point or the repair quality is unstable, the whole surface is uneven or intermittent high point, even if the place is polished, and the repair and processing again;

(2) According to the technical agreement, the single side of the repaired surface is 0.85mm.
However, after processing according to the actual corrosion state of the housing, there are four sizes of repairs up to 7~8mm. The processing plan can be adjusted to the laser additive remanufacturing surface to be processed according to the original requirements, and the size of the related products should be changed.

(3) Since the repair surface is a side elevation, the coaxial powder feeding can easily cause the powder blocking phenomenon, and the lateral pneumatic powder feeding can be used, which needs to adjust the proper powder feeding pressure to ensure that the powder feeding into the molten pool is even, otherwise easy to cause the alloy layer of thin thickness, surface smoothness, repair quality.

6. Conclusions
(1) Through the analysis of the mill housing wear mechanism, the main failure mode of the housing is corrosion wear failure.

(2) Through mechanical performance experiments, it is proved that the Fe45+5%WC alloy layer has good wear resistance and impact toughness, which meets the requirements of the actual working conditions of the housing.

(3) Observe the appearance and morphology of the alloy layer and analyze the surface by metallography: The alloy layer and the matrix exhibit a metallurgical bond, and the surface of the alloy layer has no obvious macroscopic and microscopic cracks, pores and other defects.

(4) The use of laser additive manufacturing to repair the mill housing can achieve the purpose of strengthening the mill housing, the repair process is reliable, and the alloy layer has excellent performance.

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