Crack Elimination and Surface Quality Enhancement of the Wear-resistant Layer on Guide Slippers of Coal Cutting Machines

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Abstract. In order to enhance the surface quality and avoid the cracking problem of the wear-resistant layer on guide slippers of coal cutting machines, an automatic welding system was employed for the overlaying welding production. By regulating the welding parameters, including the welding path and speed, the surface flatness and quality were greatly reduced. The cracks at the arc extinguishing positions were effectively eliminated. As compared to the conventional manual welding, the automatic welding not only reduced the machining allowance, but also increased the production rate and the service life of the guide slippers.

Keywords: Guide slipper, Wear-resistant layer, Overlaying welding, Coal cutting machine

1. Introduction
Guide slipper is one of the most important components of coal cutting machines. In order to guarantee the stable operation of the coal cutting machines, it is necessary to build a wear-resistant layer with high hardness for protecting the guide slipper surface, since the multidirectional high-duty load acts on the guide slipper when the coal cutter works [1]. In the studies of wear-resistant layer on guide slipper surface, extensive efforts have been devoted to the aspects of welding process, heat treatment, and its abrasion mechanism. The engineers and scientists selected optimized welding parameters from numerous welding experiments [1,2]. These experimental studies not only focused on the base metals and fillers, but also concerned the types of fusion welding processes. However, it is universal that the wear-resistant layer fabricated by manual welding has poor surface quality, and the cracking problem is usually encountered in the stage of extinguishing the arc [3,4]. In the previous wear-resistant layer fabrications by manual welding, the welding quality is essentially determined by skill level of the operating workers. In general, the machining allowance of the welding layer is 3~5 mm, and the cracking problem is usually visible on the surface of the welding layer.

In the present work, an automatic welding system is employed to produce the wear-resistant layer on guide slippers of the coal cutting machines. The welding processes were performed by using various welding parameters. As compared to the guide slippers with wear-resistant layers produced by conventional manual welding, the surface quality of the welded layers was enhanced, and the machining allowance of the welding layer was reduced as well.

2. Experimental
In the present study, the wear-resistant layers on the guide slippers of the coal cutting machines were fabricated by means of automatic overlaying welding. Figure 1 illustrates the sketch of the automatic welding workstation. It is shown that the workstation consists of an L-shaped welding positioner, a
KUBA welding robot, automatic torch cleaning station, and a welding machine. As illustrated by the text in blue color, the processed guide slipper is positioned on the L-shaped welding positioner, and the overlaying welding is performed by the welding torch carried by KUBA robot. Therefore, the wear-resistant layers could be deposited pass by pass on the guide slipper surfaces in different directions, which are coherently fabricated through the cooperation between the KUBA robot and the L-shaped positioner. In the welding process, all of the eight guide surfaces on the guide slipper could be reached by welding torch, which could guarantee the integrity of the finishing surfaces.

Figure 1. Sketch of the automatic welding workstation.

The MJR guide slippers were manufactured by the 27SiMn steel. In the overlaying welding process, the feeding wire was selected as the DG09 welding wire. The chemical compositions of the 27SiMn steel and the DG09 welding wire are listed in tables 1 and 2, respectively.

| Table 1. Chemical composition of the 27SiMn steel (weight percent, wt. %). |
|-----------------------|---|---|---|---|---|---|
| C | Si | Mn | S | P | Fe |
| 0.3 | 1.2 | 1.2 | 0.031 | 0.032 | Bal. |

| Table 2. Chemical composition of the DG09 welding wire (wt. %). |
|-----------------------|---|---|---|---|---|---|
| C | Cr | Mo | Mn | Si | S | P | Fe |
| 0.5~1.0 | 6.0~10.0 | ≤1.0 | ≤1.0 | 0.3~1.0 | ≤0.035 | ≤0.035 | Bal. |

Before starting the overlaying welding experiment, the equivalent carbon content was calculated to evaluate the weldability of the guide slippers fabricated by the 27SiMn steel, which could provide guidance for the optimization of the welding process. For structural alloy steels, the equivalent carbon content is calculated by the AWS D1.1 equation [5]

\[ C_{eq}^{C} = C_{C} + C_{Mn} / 6 + (C_{Cr} + C_{Mo} + C_{V}) / 5 + (C_{Ni} + C_{Cu}) / 15 \]  

(1)

where the symbols on the right-hand side represent the concentrations of the alloying components. For the 27SiMn steel, the equivalent carbon content is computed as \( C_{eq}^{C} = 0.5 \) wt.% by substituting the
chemical composition listed in table 1 into equation (1). Since \( C_C^{eq} \) is in the range from 0.4 to 0.6 wt.\%, a preheating procedure before welding and a slow cooling rate after welding are usually required for prevent the initiation of the cracks [6-8].

In the present work, the preheating temperature, \( T_0 \), was selected according to the following equations [9]

\[
P_{cm} = C_C + C_{Mn} / 20 + C_{Si} / 30 + C_{Ni} / 60 + C_{Cr} / 20 + C_{Mo} / 15 + C_{V} / 10
\]

\[
P_v = P_{cm} + [H] / 6 + h / 600
\]

\[
T_0 = 1400P_v - 292
\]

where \( P_v \) and \( P_{cm} \) are the cold cracking sensitivity and its index, respectively. [H] is the hydrogen content in the deposited metal, and its unit is ml/100 g. \( h \) is the thickness of the steel slab. As calculated by equations (2-4), the preheating temperature, \( T_0 \), was set in the range of 260~280 °C in the present work.

In the process of overlaying welding, the heat input is calculated by [10]

\[
Q = k \frac{U \cdot I}{v}
\]

where \( k \) is the thermal efficiency coefficient. \( U \) and \( I \) are the voltage and current during welding, and \( v \) is the welding speed. For the case of overlaying welding in the present work, the thermal efficiency coefficient was determined as \( k=0.8 \). By substituting the welding parameters into equation (5), the heat input values for three cases are \( Q_1=0.419 \), \( Q_2=0.347 \), and \( Q_3=0.258 \) kJ/mm, respectively.

Since the emergence of cracks in the welded wear-resistant layer is related to arc extinguishing, the arc extinguishing position and welding tracks in the automatic welding were modified. Figure 2 illustrates the original and modified welding paths in the automatic welding processes. As presented, the thick lines represent the welding tracks. In the original path, the arc extinguishing position lay above the normal welding track, so that an oblique track of the welding torch was needed. In the modified path, however, the arc extinguishing position was changed to the end of the welding track, and the space between the adjacent tracks was also decreased. By modifying the welding path, the oblique movement of the welding torch in the original welding path was unnecessary, and the heat dissipation during welding became more uniform.

![Figure 2. Schematic sketch of the welding paths and arc extinguishing positions.](image)

### 3. Results and Discussion

#### 3.1. Effects of Automatic Welding and Elimination of Cracks

In the conventional fabrication of the wear-resistant layer, the manual welding was employed broadly,
but the problem of unstable welding quality is usually encountered. Figure 3 presents the photographs of the overlaying welding surfaces by manual welding and automatic welding, respectively. It is obvious that the products obtained from manual welding have poor surface quality. In the case of automatic welding, the welding surface is found to be quite flat, which could reduce the final machining allowance. As compared to the conventional manual welding, the surface quality of the welded wear-resistant layer obtained from automatic welding became much more stable. Additionally, the production efficiency of overlaying welding of the wear-resistant layer was greatly increased by the automatic welding.

**Figure 3.** Photographs of overlaying welding surface fabricated by manual welding and automatic welding.

For the case of automatic welding by using the original path, the sample taken from the arc extinguishing position was ground and polished. Figure 4 shows the micrograph of the microstructure, where the cracks and dendrites are clearly visible. It can be seen that the cracks propagated along the grain boundaries. This can be attributed to that the sudden arc extinguishing led to a high cooling rate, and the solidification took place rapid. As a result, due to the shrinkage effect of solidification, the residue liquid was unable to feed the voids among the grains, and thus the cracks emerged and propagated at the positions of arc extinguishing. Additionally, due to the partitioning effect during solidification, the solute atoms and impurities were rejected into the residue liquid phase. In the arc extinguishing position that solidified at latest, the weld pool center was enriched by the impurities. Thus, the segregation in arc extinguishing position was more serious than the other regions, which also facilitated crack propagation in the end stage of welding.
Then, we adopted the modified path and arranged the parameters in the automatic welding processes. The experiments indicated that the decrease of the welding current and the increase of the welding speed resulted in a smaller heat input, which could prevent the crack emergence and propagation. In addition, the preheating procedure was also required, which has been demonstrated in the practical manufacturing process.

3.2. Enhancement of Surface Quality of the Wear-resistant Layer

In order to enhance the surface quality of the wear-resistant layer fabricated by automatic overlaying welding, the welding parameters were regulated. Since the flatness of the overlaying welding surface could determine the machining allowance, it is necessary to increase the surface flatness to reduce the final machining allowance [11]. In our previous products, the overlaying welding layer present a wavy configuration, and obvious height differences existed between the crest and trough of the waves. The surface flatness was measured to be 1.8 mm, which denotes that the surface quality was rather poor. Figure 5 presents the metal-inert gas (MIG) overlaying welding path used for fabricating wear-resistant layer in the present work. In figure 5, ST represents the step space between the adjacent welding tracks. Table 3 lists the welding parameters, the otherwise conditions kept identical. Based on the requirements of the construction process, two welded layers were needed, and the overall thickness should exceed 7.0 mm.

![Figure 4. Micrograph of cracks in the welded wear-resistant layer.](image)

![Figure 5. Schematic sketch of the MIG overlaying welding path by using the automatic welding workstation.](image)
Table 3. Welding parameters for the automatic MIG overlaying welding.

| Sample NO. | Welding speed (m/min) | ST (mm) | Thickness of welding layer (mm) | Surface flatness (mm) |
|------------|-----------------------|---------|---------------------------------|----------------------|
| 1          | 1.2                   | 4-5     | 7.34                            | 1.4                  |
| 2          | 1.15                  | 4.8     | 7.48                            | 0.8                  |
| 3          | 1.5                   | 4-5     | 6.68                            | 1.0                  |
| 4          | 1.3                   | 4-5     | 6.96                            | 0.8                  |

Figure 6 shows the macrographs of the wear-resistant layers fabricated by overlaying welding by using the parameters listed in table 3. As compared in table 3, the thicknesses of samples 3 and 4 are smaller than 7 mm due to the high welding speeds, and these samples are difficult to satisfy the subsequent machining process. It can be seen in figure 6 that sample 2 has the highest surface quality. The high surface quality of sample 2 could also be recognized in table 3, since it has the lowest surface flatness. In the subsequent practical production, the welding parameters for sample 2 was employed.

Figure 6. Macrograph of the wear-resistant layers fabricated by automatic overlaying welding by using the parameters listed in table 3.

4. Conclusions
In this study, an automatic welding system is used to replace the conventional manual welding for producing the wear-resistant layer on the guide slippers of coal cutting machines. It is found that the surface quality and production efficiency were greatly enhanced by using the automatic welding system. Through various overlaying welding experiments by the automatic welding system, the effects of welding parameters on the surface quality of the welded layer were investigated, including welding path, speed, and extinguishing arc procedure, and the cracking problem at the arc extinguishing position was avoided. The surface flatness was improved from previous 2 mm to present 0.8 mm, and the machining allowance was reduced from previous 4 mm to present 1.5 mm. These improvements simplified the subsequent processing and thus reduced the production costs. Our future work aims at the ultimately unmanned production of the wear-resistant layer, which follows the design of auto-flip
and precise positioning of the guide slippers.

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