Surfacing of Rapidly-Wearing Parts

A S Nazarko and R L Plomodyalo

Federal State Budgetary Educational Institution of Higher Education “Kuban State Technological University”, 2 Moskovskaya Street, Krasnodar, 350072, Russia

E-mail: nazarkoaleksandr@rambler.ru

Abstract. This paper considers the possibility of creating cast rods for surfacing of rapidly-wearing tillage tool parts of agricultural machinery, which would not contain scarce alloying elements and provide a wear-resistant deposited metal having high hardness and high resistance to crack formation in hardened condition. It was found that with an increase in boron concentration to 0.7 ... 0.8%, the amount of boride eutectic increases, which helps to prevent crystallization cracks, and the impact toughness first increases, and then slightly decreases, which is associated with the appearance of large boride inclusions.

1. Introduction

In surfacing rapidly-wearing tillage tool parts, most widely applied in practice are “Sormite No. 1” trademark electrodes containing a large number of scarce alloying elements - cobalt, tungsten, nickel, chromium, molybdenum, etc., which dramatically increases the manufacturing costs.

In solving the problem of reducing the amount of scarce alloying elements, as well as obtaining a wear-resistant deposited metal with high hardness and high resistance to crack formation in hardened condition, we proceeded from the following premises. Since the cooling rates of the deposited metal in the process of argon-arc surfacing and during air hardening are sufficiently close, when choosing a type of deposited metal, it is advisable to use air-hardening chromium steels of martensitic class as a basis. As far as is known, the hardenability of steels, i.e. their capability to increase their hardness, is mainly determined by their carbon content. To ensure the maximum hardness of martensite, the carbon content in it should be at least 0.5...0.6 % [1].

Chromium reduces the critical hardening rate, improves hardenability and forms special carbides, due to which the hardness and wear resistance of rapidly-wearing tillage tool articles increase. The chromium content in such steels can vary over a fairly wide range and reach 11 ... 13%.

To improve the hardenability and wear resistance of chromium steel, it is alloyed with manganese and silicon which are traditional deoxidizers of the weld pool when surfacing with cast rods [2]. The content of manganese in steels for the manufacture of tillage tools of agricultural machinery is usually 0.9...1.2 %; the amount of silicon can reach 3...5 %, however, the bending strength and impact toughness decrease.

Also of interest is the alloying of deposited metal with boron; it can be performed by using an affordably priced FB20 grade ferroboron introduced into the blend composition when smelting cast rods in a high-frequency induction furnace. Boron, even at low concentrations (up to 1%), significantly increases the hardness and wear resistance of deposited metal, but, as a rule, deteriorates its impact resistance [3].
2. Experimental section

Using the methods of mathematical design, we studied the "composition-properties" relationship for the deposited metal containing 0.4 ... 0.8% carbon, 1.0 ... 2.0% silicon, 7.0 ... 11.0% chromium, 0.2 ... 1.0% boron, as well as about 0.5% manganese and 0.2% titanium (the latter was added to the composition of cast rods as a processing aid).

For obtaining static models as second-degree polynomials, a design of Type Na-4 was used [4]. The variability intervals of the concentrations of alloying elements are presented in Table 1.

Table 1. Variability intervals of the concentrations of alloying elements.

| Factors              | C   | Cr  | Si  | B   |
|----------------------|-----|-----|-----|-----|
| Base level           | 0.6 | 9.0 | 1.5 | 0.6 |
| Variability interval | 0.2 | 2.0 | 0.5 | 0.4 |
| Upper level          | 0.8 | 11.0| 2.0 | 1.0 |
| Lower level          | 0.4 | 7.0 | 1.0 | 0.2 |

The number of deposited metal properties that determine the operational reliability of tillage tools of agricultural machinery should include hardness, resistance to abrasive wear, bending strength, as well as heat resistance (under severe conditions, the tillage tools of agricultural machinery can be heated up to 200...300 °C).

Wearing tests of the deposited metal were carried out according to the well-known technique on a machine SMT-1. As a counterbody, specimens made of steel 45, hardened to 50 HRC, were used. The wear characteristic was the mass loss G_{wear}.

The bending strength $\sigma_{bending}$ was determined on specimens of 30x6x6 mm in size with a surface finish of $R_a = 0.4 \mu m$. To exclude errors introduced by friction forces, we used a device with roller bearings, the distance between which was 20 mm. The loading rate was 100 N/sec.

The characteristic of the heat resistance $T_{50}$ of the deposited metal was a temperature of two-hour tempering after which the hardness decreased to 50 HRC.

One of the most common and critical defects encountered in surfacing alloy steels of martensitic class are cold cracks. The metallographic studies performed during preliminary experiments showed that in most cases cold cracks developed from small solidifying cracks. Therefore, when studying the "composition-properties" relationships, the resistance of deposited metal to hot cracking was chosen as one of the optimization parameters. For the quantitative assessment, the Apblett-Pellini test was used [5, 6]. The composite specimens were made from plates of steel 45 with dimensions of 100x15x15 mm. The surfacing was carried out in a mode of $I_w = 120 ... 140$ A. The criterion for the resistance of deposited metal to hot cracking was the percentage of the cross-sectional area of the bead occupied by hot cracks ($S_{cr}$).

3. Results and discussion

The chemical composition and test results of the deposited metal are shown in Table 2.

After processing the test results using multivariate regression analysis methods with sequential exclusion of non-significant variables, the following regression equations were obtained:

$$HRC = 51.911 - 5\sigma893Si + 20.231 B - 1.0723 C \times Cr + 11.065 C \times Si - 0.66663 Cr \times B + 0.049980 Cr^2 - 7.3584 B^2;$$

multiple correlation coefficient $R = 0.9585$

residual standard deviation $\sigma_0 = 0.48$

significance level of the regression coefficient $P \leq 0.006$
The analysis of the influence of alloying elements on the properties of the deposited metal with a constant content of the other elements in it showed, in particular, that increasing the boron content in the studied range increases the resistance of the deposited metal to formation of hot cracks. The favorable effect of boron can be accounted for by the appearance of boride eutectic in the structure of the deposited metal. In the deposited metal of Type 60X8C2PT, it appears already at a boron content of 0.2%, but in small amounts – insufficient for “healing” the small breaks of metal formed during primary solidification. With an increase in boron concentration to 0.7 ... 0.8%, the amount of boride eutectic also increases, which helps to prevent solidification cracks. With increasing the boron content in the specified range, the impact resistance first increases, and then decreases slightly, which is apparently associated with the appearance of large inclusions of borides [7].
The search for the optimal composition of deposited metal was carried out using a generalized objective function taking into account the values of individual indicators, since in this case there are several optimization parameters (hardness, strength, wear resistance, etc.). The analysis of literature data and production experience has shown that the deposited metal of tillage tools of agricultural machinery should meet the following requirements: HRC ≥ 58, $\sigma_{\text{bending}} \geq 2000$ MPa, $T_{50} > 500$ °C, $G_{\text{wear}} \leq 20$ mg/mm², $S_{\text{cr}} = 0$.

As a result of the search under the given constraints, the optimal chemical composition of deposited metal was determined with the following expected properties: HRC 58, $\sigma_{\text{bending}} = 2050$ MPa, $T_{50} = 560$ °C, $G_{\text{wear}} = 18$ mg/mm², $S_{\text{cr}} = 0$.

Cast rods were developed to obtain the tailored composition of deposited metal.

The structure of the metal, deposited with the cast rods, is: martensite, carbides, and borides in the presence of a moderate amount of retained austenite (figure 1).

The results of testing the specimens of the Type 60X8C2PT metal deposited with the developed cast rods are given in Table 3. As can be seen, the metal deposited with the cast rods is significantly superior in properties to steel grades L53 and L65 deposited with “Sormite No. 1” electrodes.

![Figure 1. Microstructure of the metal deposited with the cast rods, x500.](image)

| Type of metal | HRC  | $G_{\text{wear}}$, mg/mm²² | $\sigma_{\text{bending}}$, MPa | $T_{50}$, °C |
|--------------|------|---------------------------|------------------------------|-------------|
| 60X8C2PT     | 58/59| 18/19                     | 2050/2000                    | 560/550     |
| L53          | 53   | 32                        | 2050                        | 570         |
| L65          | 61   | 34                        | 1050                        | 750         |

Note. The calculated data are in the numerator, the experimental data are in the denominator

### Conclusion

Based on the experimental results obtained, it can be concluded that 60X8C2PT surfacing cast rods can be used both in the manufacture and in the repair of tillage tools of agricultural machinery.

The cast rods do not contain scarce alloying elements and provide a wear-resistant deposited metal having high hardness and high resistance to crack formation in hardened condition.
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