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# The effect of nitrogen alloying to the microstructure and mechanical properties of martensitic stainless steel hardfacing

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ABSTRACT

The effect of nitrogen additive on the microstructure and mechanical properties of martensitic stainless steel hardfacing was investigated in this work. The phase structure of the hardfacing was analyzed by X-ray diffraction (XRD). The microstructures with and without nitrogen additive were observed by field emission scanning electron microscope (FESEM) and transmission electron microscope (TEM). The mechanical properties of the hardfacing were measured, and the fracture surfaces were observed by FESEM. The equilibrium phase diagram and phase precipitation rule were calculated by ThermoCalc software. The results show that, by replacing carbon with nitrogen in hardfacing, the martensitic lath is refined, and the segregation and precipitation on prior austenite grain boundary cannot be found. In addition, the mechanical properties of the hardfacing can be improved obviously after composition optimization, in which, the yield strength and tensile strength are increased from 884 MPa and 996 MPa to 1078 MPa and 1554 MPa respectively. Meanwhile, the ductile of the hardfacing is significantly increased. The fracture surface is transformed from brittle intergranular fracture into ductile transgranular one.



## 1. Introduction

Continuous casting roller is a key component in continuous casting and rolling production. With high heat resistance, abrasive resistance, corrosion resistance and mechanical properties, the martensitic stainless steel was usually chosen to manufacture the continuous casting roller [1–3]. During continuous casting and rolling production, the continuous casting roller always failed because of its lower mechanical properties. The failed roller could be remanufactured by hardfacing method to restore its initial shape and size, and obtain higher mechanical properties.

It is recognized that nitrogen as an alloy element can reinforce Fe-based alloy [1,4]. With the development of high-pressure melting and higher nitrogen content in steel, the effect of microstructure and properties caused by nitrogen additive in Fe-based alloy have been investigated deeply [5–10].

Nitrogen additive in austenite stainless steel has been abundantly studied [11–13]. Because the radius of nitrogen atom is smaller than that of carbon atom, researchers found that nitrogen atoms could solute in austenite instead of carbon atoms, especially the strength [11] and corrosion resistance [14,15] of austenite stainless steel can be improved obviously by nitrogen additive. J.W. Simmons [6] reviewed that the mechanical, corrosion and fatigue properties of the high nitrogen stainless steel can be improved by nitrogen additive. Werner [16] believed that nitrogen as an element in austenite stainless steel is more effective on solid-solution strengthening and grain refinement strengthening than carbon. Balachandran et al. [17,18] found that with increasing nitrogen content, the austenite stability can be improved significantly. Soussan [19] also found that by nitrogen additive, the strain hardening rate of the austenite alloy is improved greatly. Lo et al. [20,21] discovered that the strength of Fe-based alloys can be improved significantly by nitrogen additive. Meanwhile, the ductility is not decreased.

In recent years, researchers have begun to focus on the effect of nitrogen additive in martensitic stainless steel. X.P. Ma [22] investigated the properties of the martensitic stainless steel of 13Cr5Ni1Mo0.025Nb0.09V0.06N, and found that the formation tendency of ferrite and deformation induced martensite transformation can be reduced. Lee et al. [23] found that it is beneficial to improve creep resistance and fatigue abrasive resistance by N additive.

At present, researchers are just beginning to study the effect of nitrogen additive on hardfacing. Yang [24] studied carbonitrides precipitations in martensitic hardfacing, which could improve abrasion resistance and fatigue flake resistance. Moon [25,26] made a systematic study on the mechanical properties and microstructure of heat affect zone in high nitrogen stainless steel. However, up to now, the effect of nitrogen additive on the microstructure and mechanical properties of martensitic hardfacing has not been found.

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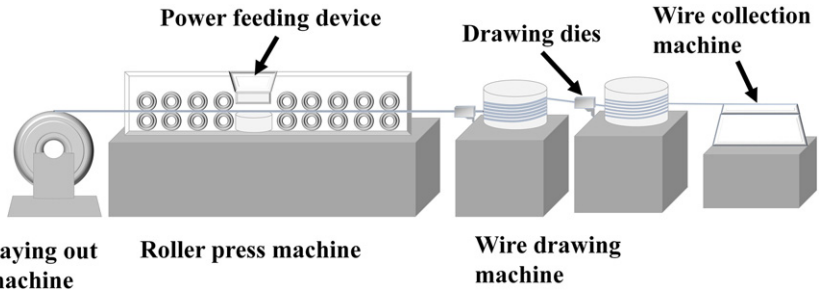


**Fig. 1.** Diagrammatic view of flux-cored wire manufacturing.

**Table 1**
Chemical composition of H08A.

| Element | C | Si | Mn | Cr | Ni | Cu | S | P |
|---|---|---|---|---|---|---|---|---|
| Content (wt.%) | ≤0.10 | ≤0.03 | 0.35–0.60 | ≤0.20 | ≤0.30 | ≤0.20 | ≤0.03 | ≤0.03 |

**Table 2**
Chemical composition of the hardfacings (wt.%).

| Element | C | N | Si | Mn | Cr | Mo | Ni | V | Nb |
|---|---|---|---|---|---|---|---|---|---|
| No. 1 | 0.19 | – | 0.36 | 1.18 | 12.8 | 0.5 | 1.3 | – | – |
| No. 2 | 0.095 | 0.07 | 0.328 | 1.24 | 13.22 | 2.21 | 2.63 | 0.155 | 0.049 |

**Table 3**
Chemical composition of Q235.

| Element | C | Si | Mn | S | P |
|---|---|---|---|---|---|
| Content (wt.%) | ≤0.20 | ≤0.35 | ≤1.40 | ≤0.03 | ≤0.03 |

In our previous research, the high-alloyed martensite in hardfacing with different carbon contents has been investigated [27,28]. Based on the effect of carbide precipitation on the hardfacing abrasive resistance, such as nitrided ferrochrome, ferromolybdenum, ferronickel, ferrovanadium, ferroniobium and so on were added in the flux core to optimize flux-cored wire. The optimized flux-core wire could obtain a better microstructure and mechanical property of the hardfacing, which may provide guidance for hardfacing remanufacturing of the continuous casting roller.

## 2. Experimental materials and methods

As shown in Fig. 1, the flux-core wire was manufactured with rolling and drafting process. The outer shell of the flux-cored wire was the low-carbon steel strip of H08A, whose chemical composition is listed in Table 1. The core powders mainly consist of ferrochrome, ferromanganese, ferrosilicon, molybdenum powder, and nickel powder and so on. No. 1 wire was the traditional martensitic stainless steel flux-cored wire, which has been widely used in actual application for hardfacing continuous casting roller. No. 2 wire was the added nitrided ferrochrome flux-cored one, as is listed in Table 2, the composition of No. 2 welded hardfacing was optimized. The chemical compositions of the hardfacing were determined by using Advant/p-381 X-ray fluorescence spectrometer and CS-8800 high frequency infrared carbon sulfur analyzer. In this paper, substrate steel for the welding surface was prepared from steel plate of Q235, whose chemical composition is listed in Table 3. With the method of submerged-arc hardfacing, five layers were welded onto the surface of each substrate steel. The parameters of hardfacing process are listed in Table 4.

Firstly, specimens with size $10 \times 10 \times 10\ mm^3$ were cut off from the middle of the hardfacing by electrical discharge wire-cutting. The specimens were ground on SiC waterproof paper with grit from 150 to 1200, and were polished with diamond compound polishing paste. The phase structure of the hardfacing was analyzed by X-ray diffraction (XRD) using a D/max-2500/PC diffractometer equipped with Cu-Kα radiation, with the scanning range $40° \le 2\theta \le 100°$ and a step size of 0.02°and the dwell time was 2 s. After etched with aqua regia, the microstructure and elements segregation of the hardfacing were analyzed by using a Hitachi S4800-IIfield emission scanning electron microscope (FESEM) and energy dispersive X-ray spectrometry (EDS). The crystal structure was determined by transmission electron microscope (TEM) JOEL 2010.

Three tensile specimens parallel and perpendicular to the welded trace were taken from the welded layer to examine the yield and tensile strength by using Inspekt Table 100 type electromechanical universal testing machine. The size and shape of the specimens have been inserted in Fig. 2. Then the fractographies were analyzed by using FESEM.

At last, ThermoCalc software was employed to calculate the phase diagram and the variation of different phase fractions as a function of temperature of the hardfacing.

## 3. Experimental results

### 3.1. Microstructure

#### 3.1.1. Phase structure

The XRD diffraction pattern for No. 1 hardfacing in comparison with that for No. 2 hardfacing is shown in Fig. 3. The main phase of both No. 1 and No. 2 hardfacing is α-Fe, which may be martensite. Moreover, a little part of γ-Fe phase was found in No. 1 hardfacing, which might be retained austenite. One can immediately realize that the (110) diffraction peak in both No. 1 and No. 2 hardfacing is extremely strong. In addition, the (211) diffraction peak is stronger than the (200) diffraction peak in No.1 hardfacing. On the contrary, in No. 2 hardfacing, the (200) diffraction peak is stronger.

The structure was refined on the XRD diffraction patterns with Rietveld method. It can be found that $5.5 \pm 0.5\%$ γ-Fe phase exists in No.1 hardfacing. No γ-Fe phase diffraction peak is found in No. 2 hardfacing. Moreover, no diffraction peaks of carbides, nitrides and carbonitrides can be found in the hardfacing.

**Table 4**
Hardfacing processing parameters.

| Wire diameter (mm) | Voltage (V) | Current (A) | Travel speed (mm/s) | Substrate steel thickness (mm) | Layer thickness (mm) |
|---|---|---|---|---|---|
| 2.8 | 28–30 | 280–300 | 5 | 20 | 15 |