Trial Production of Stainless Steel Cladding Rebar by Liquid-solid Casting and Hot Rolling Method

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Abstract: In the present investigation, liquid-solid casting and hot rolling method was successfully used to manufacture stainless steel cladding (SSC) rebar. Stainless square tube that was surface treated by pellet blasting treatment was preheated to 1100 °C, and then liquid carbon steel which was heating up by induction furnace to 1620 °C was filled into the tube to cast the SSC billet. SSC billet was rolled in a wire and rod plant successfully due to metallurgical bond state between the tube and carbon steel. Soaking temperature and starting rolling temperature as well as finishing rolling temperature were exhibited 1180 °C, 1130 °C and 1000 °C. Uniaxial tensile testing of SSC rebar at room temperature exhibited an extremely yield strength of 433 MPa and a tensile strength of 599 MPa, while the elongation reached 24%. Positive and negative bending experiment showed no cracks during the deformation. Through metallographic analysis, it was found that the base structure of stainless steel was ferrite, and heterogeneous phases such as martensite and ferrite was discovered near the interface of carbon steel and stainless steel.

1. Introduction

Stainless steel cladding (SSC) rebar presents excellent application prospects in the field of construction, chemical industry, petroleum industry and bridges due to the comprehensive performance, that combinates high strength and valid corrosion resistance, and lower costs comparing to the pure stainless rebar [1-3]. The outstanding anti-resistant performance is exhibited especially in the corrosive medium such as seawater and rainwater environments [4].

Currently, SSC rebar or SSC round bar were fabricated with spray forming and rolling cladding, explosive cladding, cold drawing and then rolling with rotary cone rolls, mechanical compression and rolling method, laser cladding method, the surfacing method of TIG and hot rolling. Osprey process and rolling method, which can create a metallurgical bond between the stainless steel cladding and the core steel, was applied by two American companies, SMI-CMC and MMFX. The cost for producing is about 2-5 times that of typical rebar [3]. Explosive cladding was a solid state welding method, dissimilar metals were cladded by instantaneous blast impact [5]. A patent, which relates to a way of manufacturing a clad bar and is characterized in that a columnar core member is fitted in a cylindrical outside layer member and the resulting assembly is cold drawing and then rolling with rotary cone rolls, was published by Kazuyuki Nakasuji and Chihiro Hayashi [6]. A method, expounded by A. G. Cacace et al., was described to produce SSC bar from a SSC billet, which comprise a core of finely divided ferrous swarf.
compacted into briquettes in a stainless steel jacket, and then the SSC billet was rolled in a suitable temperature at which the core of the SSC was plastic enough [7]. It was reported that SSC rebar was manufactured by the surfacing method of TIG [8]. J. Tuominen et al. used laser cladding method to manufacture SSC round bar, the cladding layer and base metal respectively were St21 and S355 as well as In 625 and 42CrMo4 [9]. According to the study of M. A. Mudhaffar et al., hot rolling method was used to manufacture SSC rebar [10].

These methods can make SSC rebar depending on production condition, however, there were few literature materials about the fabricating of SSC rebar which is manufactured using the combination of liquid-solid casting and hot rolling method.

![Fig. 1. Arrangement plan of experimental equipment: a) surface treatment of stainless steel square tube with pellet blasting method, b) liquid-solid casting process and c) hot rolling of SSC billet.](image)

Figure 1 shows the concept of liquid-solid casting and hot rolling method. The stainless steel square tube was surface-treated and made up into a SSC billet which was covered by stainless steel on the surface of casting carbon billet except for the two cross sections (Figs. 1(a) and (b)). Built-up billet is hot-rolled to produce SSC rebar (Fig. 1(c)).

In the present investigation, liquid-solid casting and hot rolling method was attempted in a steel plant which manufactured wire and rod products. SSC rebar can be produced successfully by liquid-solid casting and hot rolling method, and not only the fine metallurgical bonding preference of the interface of SSC billet was achieved, but also the subsequent steady rolling of SSC rebar was displayed.

2. Experimental

2.1 raw materials

The composite material was designed to meet the demands of construction application in which yield strength and tensile strength should be satisfied the minimum value of 400MPa and 540MPa. Methods of micro-alloying strengthening of Ti and solution strengthening of C, Mn, Cr of base metal were applied to guarantee the overall mechanical property of SSC rebar. And cladding metal was Cr13 due to the overall performance of stainlessness and lower costs.

The chemical compositions of the stainless steel and carbon steel are given in Table 1.

| Table 1. Chemical composition of stainless steel and carbon steel (mass%). |
|-----------------|---|---|---|---|---|---|---|---|---|---|
| Elements        | C  | Mn | Si | P  | S  | Cr | Ni | Ti | Fe |
| Carbon steel    | 0.246 | 1.24 | 0.496 | 0.011 | 0.027 | 0.20 | 0.07 | ~0.04 | Bal. |
| Cr13            | 0.026 | 0.36 | 0.410 | 0.022 | 0.012 | 12.36 | 0.13 | -   | Bal. |
2.2 producing process

2.1.1. Surface treatment. Prior to the producing of the SSC rebar, the cleanness of the stainless steel square tube was so important that strongly impacted the bonding quality. And pellet blasting treatment, which revealed the fresh metal of tube surface, was required in order to make the quality of SSC billet up to standard. The surface treatment removes the scale and other foreign matter, and the high temperature casting ensures the high bonding strength in the interface of the SSC billet and limestone water of the inner wall of tube avoids interface oxidation during casting hot rolling process.

2.1.2. Liquid-solid casting process. Liquid carbon steel, that was heating up by induction furnace to 1620℃, was filled into the stainless steel square tube which was preheated to 1100℃. Higher preheating temperature contributes to the creation of the molten state which leads to metallurgical bonding. WANG Xingyun studied the characterization of 2Cr13/9Cr18MoV/2Cr13 composite stainless steel by centrifugal casting and hot rolling method [11].

2.1.3. Hot rolling process. The SSC billet was heated up in the furnace for 3 hours after the liquid-solid casting process. Taking the different hot working characteristics of stainless steel and carbon steel into consideration, soaking temperature and starting rolling temperature as well as finishing rolling temperature were exhibited 1200℃, 1180℃ and 1000℃ (Fig 2). In aims to reduce the producing of brittle phase such as martensite which deteriorate the plastic performance such as bending performance, air cooling strategy was applied.

Original dimension of casting carbon billet was 150mm*150mm*300mm, and stainless steel tube of 5 mm thickness was assembled with the casting carbon billet. And then the SSC billet was rolled from the rectangle section of 160mm*160mm down to a circular section of Φ20 mm after 15 passes. Due to the shortness of SSC billet, jointed billet was used to ensure rolling stability. Fig. 3 (a) shows the macroscopic features of surface of SSC billet. The length of billet should be great than or equal to 2800mm due to constraints of device in workshop, SSC billet was welded with carbon billet to satisfy the least rolling length of device, the jointed billet was comprised with 2600mm carbon steel billet, 300 mm SSC billet and 300mm carbon steel billet.Fig. 3(b) exhibits stable rolling process and fig. 3(c) presents bright and clean surface of SSC rebar after polishing.

During hot rolling period of SSC billet, through severe rolling in high temperature, sound metallurgical bonding of the two metals was achieved at the clad interface of SSC rebar.

Fig 2. Rolling temperature schedule of SSC billet
Fig. 3. (a) macroscopic feature of jointed billet, (b) SSC rebar of Φ20mm after hot rolling, and (c) SSC rebar of Φ20 mm after polishing.

2.1.4. Metallographic corrosion method. To increase the metallographic morphology contrast of the interface, a solution of 5mL nitric acid and 95mL ethanol was used and aqua of 4g trinitrophenol, 5ml hydrochloric acid and 95mL ethanol was used to observe the structure of both the carbon and stainless steel substrates.

3. Results and Discussion
Mild carbon steel can be successfully cladded with Cr13 stainless steel to fabricate SSC rebar.

3.1. Metallographic morphology

Fig. 4. Cladding interface morphology (a) of SSC billet, and (b) of SSC rebar.

Fig. 4(a) shows a flat interface of SSC billet, which is better than the wave like interface when explosive cladding was applied. Fig. 4(b) exhibits clear interface of SSC rebar which was corroded with nitric acid alcohol. There is no pores and crack near the interface of both SSC rebar. Fig. 4(c) showed the metallographic structure of both carbon steel and stainless steel while aqua of trinitrophenol, hydrochloric acid and ethanol was used. It was obviously observed that heterogeneous phase of martensite and ferrite exists in the transition region due to the diffusion of key elements such as C, Cr, Mn which decrease the critical rate of phase transformation. And obvious decarbonization region was presented near the interface of SSC rebar in carbon side A similar situation has been found by other scholars [12,13].
3.2. Mechanical properties

![Macrographs of the SSC rebar after bending experiment](image)

**Fig. 5.** Macrographs of the SSC rebar after bending experiment: (a) positive bending and (b) negative bending.

| Table 2. Mechanical properties of SSC Rebar. |
|--------------------------------------------|
| Type of test | YS, MPa | UTS, MPa | %EI |
|---------------|---------|----------|-----|
| 1             | 433     | 599      | 24  |

Fig. 5 shows there is no crack near bending position whether it is subjected to positive or negative bending. Experimental result also suggests that interface is metallurgical bonding and has some ductility. Uniaxial tensile testing of SSC bar by liquid-solid casting and hot rolling method at room temperature exhibits an extremely high yield strength of 433 MPa and a tensile strength of 599 MPa, while the elongation reaches 24%. These mechanical property satisfies the requirements of *GBT 36707-2018 Hot rolled carbon steel and stainless steel clad bars for the reinforcement of concrete* and meet the standard of the engineering application.

4. Conclusion

Mild carbon steel can be successfully cladded with Cr13 stainless steel by liquid-solid casting and hot rolling method. The mechanical quality of manufacturing SSC rebar can meet the requirements of Chinese hot rolling composite rebar. The following conclusions were conducted.

1. Uniaxial tensile testing of SSC rebar at room temperature exhibited an extremely yield strength of 433 MPa and a tensile strength of 599 MPa, while the elongation reached 24%. Positive and negative bending experiment shows no cracks during the deformation.

2. SSC billet shows metallurgical bonding interface by liquid-solid casting method while pouring temperature of carbon steel and preheating temperature were 1620°C and 1100°C respectively. And SSC billet also exhibited flat metallurgical bonding interface.

3. The base structure of stainless steel of SSC rebar was ferrite, and heterogeneous phases such as martensite and ferrite was discovered near the interface of carbon steel and stainless steel. Decarburization area was obviously observed on carbon side near the interface due to the diffusion of carbon in high temperature.

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