Study on the Complete Decarburization of Spring Steel 55SiCrA during Rolling

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Abstract. The rolling test of 55SiCrA spring steel wire rod was carried out with different finishing rolling temperature and laying temperature. The results show that different rolling processes can form different types of complete decarburization. Through temperature measurement and metallographic examination of process samples, it is found that the surface of the rolled piece has formed a complete decarburization layer during the rolling process. However, by setting proper finishing rolling temperature and laying temperature, the deformation heat of high-speed rolling can transform complete decarburization into austenite and avoid complete decarburization of 55SiCrA spring steel wire rod.

1. Introduction
55SiCrA spring steel for automobile is mainly used in the production of suspension spring, valve spring, clutch spring, etc. Fatigue performance is one of the key targets of automobile spring. If there is complete decarburization on the surface of spring, the fatigue performance of spring will be seriously damaged. Gildersleeve[1] showed that the fatigue strength decreases with the decrease of surface carbon content.

Liu et al.[2, 3] studied the effect of temperature and oxygen concentration on the decarburization layer of 55SiCrA spring steel. The results showed that after the spring steel was insulated in the temperature range of A1-TG for 60 min in the air atmosphere, complete decarburization would be discovered on the surface. Zhang et al.[4] also showed that when 60Si2MnA was heated at 675°C to G temperature (about 912°C), the complete decarburization would be discovered. According to the equipment condition of Xingtai Steel, the development process of 55SiCrA decarburization in rolling process is studied, and the root cause of complete decarburization is analyzed.

2. Experimental
The steel selected for this investigation is spring steel 55SiCrA, size 8mm, and has the chemical composition (wt%) of 0.54 C, 0.67 Mn, 1.35 Si, 0.73 Cr, 0.012 P, and 0.010 S.

The effect of the original decarburization layer of the billet can be eliminated by the grinding treatment, and the same heating process is adopted to ensure that different billets have the same decarburization level in the heating furnace. The experiment was carried out on the high speed wire rod mill of Xingtai Iron and Steel Co. Ltd., the layout of the mill is shown in Figure 1. The final rolling temperature is set at 830°C, 880°C and 930°C, and the laying temperature is set at 820°C, 870°C and 920°C respectively.
Take the wire rod and flying shear samples of each process, which were polished and etched with 4vol% nitric acid to observe the depth and type of complete decarburization. The lowest surface temperature of rolled piece at different rolling positions was measured by hand-held pyrometer.

![Diagram of rolling mill](image)

**Figure 1.** Layout of rolling mill.

3. Results and discussion

3.1. Types of complete decarburization under different processes.

In this paper, three types of complete decarburization are defined (Figure 2), type A: no complete decarburization; type B: single point complete decarburization (length less than 200 μm); type C: long-term complete decarburization.

![Images of decarburization types](image)

**Figure 2.** Types of complete decarburization.

Different finishing rolling temperature and laying temperature are adopted, and the type of complete decarburization of wire rod is shown in Table 1.

| No. | Finishing rolling temperature (°C) | Laying temperature (°C) | Types of complete decarburization |
|-----|----------------------------------|------------------------|----------------------------------|
| 1   | 830                              | 820                    | C                                |
| 2   | 830                              | 870                    | C                                |
| 3   | 830                              | 920                    | B                                |
| 4   | 880                              | 820                    | B                                |
| 5   | 880                              | 870                    | A                                |
| 6   | 880                              | 920                    | A                                |
| 7   | 930                              | 820                    | A                                |
| 8   | 930                              | 870                    | A                                |
| 9   | 930                              | 920                    | A                                |

In Table 1, when the finishing temperature is 830°C, the type of complete decarburization is B or C, while when finishing temperature is 880°C and laying temperature is 820°C, the type of complete decarburization is B, and the type of complete decarburization of other processes is A. This shows that under the same decarburization condition, the rolling process has an effect on the complete decarburization.
decarburization of wire rod. In order to avoid serious complete decarburization of wire rod, it is necessary to select proper finishing temperature and laying temperature.

3.2. Precipitation of total decarburization.

Si content in 55SiCrA spring steel is high, and it is easy to form deep decarburization layer on billet surface in heating furnace[5, 6]. According to Fick’s second law, C content increases from the surface to the inside of the billet[7]. C content of billet surface is close to 0, and gradually increases to 55SiCrA. Then, according to the iron-carbon phase diagram, the A3 temperature in the surface and inside of the billet is different. In the surface position, A3 temperature can be considered as TG point temperature (912°C) because C content is close to 0. Therefore, when the surface temperature of the rolled piece is lower than Ar3 temperature (calculated by supercooling degree 40°C, about 870°C), the decarburization position will undergo γ→α transformation, resulting in the precipitation of proeutectoid ferrite, which is complete decarburization. Then, when the temperature of the rolled piece rises to above Ac3 temperature (calculated by superheat degree of 40°C, about 950°C), the ferrite will undergo α→γ transformation, and the complete decarburization will disappear.

![Temperature curve from roughing mill to pre finishing mill](image1.png)

**Figure 3.** Temperature curve from roughing mill to pre finishing mill.

![Microstructure of flying shear sample](image2.png)

**Figure 4.** Microstructure of flying shear sample
(a. 2# flying shear sample; b. 3# flying shear sample with finish rolling temperature sets as 880°C and 830°C; c. 3# flying shear sample with finish rolling temperature sets as 930°C)

According to the equipment status of the production line, there is no water box in front of the pre finishing mill, and the temperature of the rolled piece cannot be adjusted. Before the outset of the pre finishing mill, the temperature curves of all processes are the same (Figure 3). Between 2# to 10# rolling mill, the surface temperature of the rolled piece is lower than Ar3, and the holding time is more than 40s, until the outlet of 18# rolling mill reaches Ac3 again. Under the temperature of Ar3 for a long time, there is enough time to complete the transformation of γ→α, and the surface has formed
complete decarburization. After quenching, the microstructure of 2# flying shear samples was examined. It was found that there was a complete decarburization layer of about 40 μm on the surface (Figure 4a). There is no temperature regulating equipment between roughing mill and pre finishing mill, and complete decarburization can not be avoided in this position under the existing equipment conditions.

3.3. Austenization of complete decarburization.

When high-speed wire rod is rolled in the pre finishing mill and finishing mill, the temperature of the rolled piece is increasing. In this stage, the rolling speed is very fast, the strain rate of the rolled piece is large, and a lot of deformation heat increases the temperature of the rolled piece. According to figure 5, the temperature change between the pre finish rolling outlet and laying is that: Pre finishing outlet→2# water tank cooling→Recovery→Temperature rise in finishing→3# water tank cooling→Recovery→Laying.

![Figure 5. Temperature curve from pre finishing mill to laying.](image)

The finish rolling temperature is controlled by 2# water box, and the laying temperature is controlled by 3# water box. Different finish rolling temperature and laying temperature setting lead to different temperature curves during rolling from the outlet of pre finishing mill to laying, resulting in different types of complete decarburization of wire rod. The types and reasons of complete decarburization at different finishing temperatures are discussed below.

1. When the final rolling temperature is set at 930 °C, the rolled piece does not need to be cooled in 2# water box. Therefore, the rolled piece is cooled slowly, and the temperature is above Ar3 temperature for about 1.5s (No.7, No.8 and No.9 in Figure 5). The pre eutectoid ferrite may undergo α→γ transformation. The microstructure test of 3# flying shear sample shows that there is no complete decarburization on the surface (Figure 4c). After finishing rolling, the temperature of wire rod is close to 1100°C. At this time, even if the wire rod temperature is reduced to below Ac3 by using 3# water box, the short holding time (about 0.5s) is not enough to form complete decarburization. After laying, the wire rod is cooled rapidly and the temperature drops below Ar1 temperature rapidly, then the wire rod will not form complete decarburization.

2. When the finish rolling temperature is 880 °C, the holding time of rolled piece above Ar3 temperature is very short, and the ferrite will not undergo α→γ transformation, then the complete decarburization of rolled piece will be retained. The microstructure test of 3# flying shear sample shows that there is a complete decarburization with a depth of 20μm on the surface (Figure 4b). After finishing rolling, the temperature of wire rod rises to over 1000°C, the superheat of α→γ reaction exceeds 100°C, and the incubation period is shortened[8]. Therefore, most of the ferrite will undergo α→γ transformation during finishing rolling. When the laying temperature is 820°C, the cooling rate
of 3# water box is very fast (No.4 of Figure 5), and the untransformed ferrite cannot continue to transform, leaving on the surface of wire rod to form type A complete decarburization. When the laying temperature is above 870°C, the cooling rate of 3# water box is smaller (No.5 and No.6 of Figure 5), and the untransformed ferrite continues to undergo $\alpha \rightarrow \gamma$ transformation, so that there is no complete decarburization on the surface of wire rod.

(3) When the finishing temperature is 830°C, the microstructure of 3# flying shear sample is the same as that of 880°C, and there is complete decarburization. After finishing rolling, the temperature of wire rod rises to about 980°C (No.3 of Figure 5) and the superheat is smaller, so the $\alpha \rightarrow \gamma$ transformation cannot be carried out in the finishing mill. When the laying temperature is 920°C, the cooling rate of 3# water box is slower, and some ferrite undergo $\alpha \rightarrow \gamma$ transformation, forming type B complete decarburization on the wire rod. However, when the laying temperature is 870°C and 820°C, the ferrite does not undergo $\alpha \rightarrow \gamma$ transformation, and the complete decarburization remains on the surface of the wire rod, which is type C complete decarburization.

According to the above analysis, the deformation heat produced by high-speed rolling can increase the temperature of rolled piece, make the transformation of $\alpha \rightarrow \gamma$ be carried out smoothly, so that the ferrite is transformed into austenite again, and the complete decarburization disappears. Therefore, the proper finish rolling temperature and laying temperature can avoid the complete decarburization of 55SiCrA spring steel wire rod.

4. Conclusions
(1) Different types of complete decarburization can be formed on the surface of 55SiCrA wire rod by setting different finishing rolling temperature and laying temperature.
(2) Through temperature measurement and metallographic examination of process samples, it is found that the surface of the rolled piece has formed a complete decarburization layer during the rolling process, which is one of the reasons for the complete decarburization of 55SiCrA spring steel wire rod.
(3) By setting proper finishing rolling temperature and laying temperature, the deformation heat of high-speed rolling can transform complete decarburization into austenite and avoid complete decarburization of 55SiCrA spring steel wire rod.

5. References
[1] Gildersleeve M J 1991 Relationship between decarburization and fatigue strength of through hardened and carburizing steels Mater. Sci. Tech-lond. 7 307-10.
[2] Liu Y B, Zhang W, Tong Q and Wang L F 2014 Effects of Temperature and Oxygen Concentration on the Characteristics of Decarburization of 55SiCr Spring Steel ISIJ Int. 54 1920-26
[3] Liu Y B, Zhang W, Tong Q and Sun Q S 2016 Effects of Si and Cr on Complete Decarburization Behavior of High Carbon Steels in Atmosphere of 2 vol. % O2 J. Iron Steel Res. Int. 23 1316-22.
[4] Zhang C L, Zhou L Y and Liu Y Z 2013 Surface decarburization characteristics and relation between decarburized types and heating temperature of spring steel 60Si2MnA Int. J. Miner. Metall. Mater. 20 720-24.
[5] Shi R X, Yao C F, Hui W J, Yong Q L and Nie Y H 2008 Effect of Si on Behavior of Oxidation and Decarburization Of Medium Carbon Spring Steels Special Steel 29 19-20.
[6] Cui J, Liu Y Z and Huang X Q 2007 Investigation on Decarburizing Characteristic of Medium Carbon Spring Steel in Heating Process Hot Working Technology 36 20-23.
[7] Chen Y S, Xu X X and Liu Y 2020 Decarburization of 60Si2MnA in atmospheres containing different levels of oxygen, water vapour and carbon dioxide at 700-1000°C Oxid. Met. 93 105-129.
[8] Xu Z and Zhao L C 2004 Principle of Solid-state Phase Transformation of Matals (Science Press) pp 11-14

Acknowledgments
S & T Program of Hebei (205676134H)