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The Improvement on Decarburization of S55C for the Linear Guild-Rail in #1 Bar Mill

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Decarburized steel causes several problems, for example, lowering of hardness and fatigue life, when it is used to manufacture auto parts or mechanical parts. The main mechanism of decarburization is related to diffusion and oxidation of carbon during reheating of the billet. The key factors of the process are furnace temperature, heating time, furnace atmosphere and oxygen content, are all studied by introducing the Taguchi experiment. In this study, a more specific effect of these factors are compared and identified, which indicates decreasing furnace temperature from 1050°C to 970°C, optimizing the scheduling plan for stabilizing the furnace temperature to meet the low temperature rolling process, and lower the air-fuel ratio are essential measures to reduce decarburization. Through these improvements, the accepted decarburization rate increased from 72% to 99.86% and thus obtained annual benefits of 10.72 million NT dollars. In addition, customers can consequently benefit from reducing the sandblasting process and save 43.6 million NT dollars per year.

Keywords: Linear guide-rails, Decarburization, Heating

1. INTRODUCTION

Linear guide-rails are one of the rolling guide elements applied to robots and machines in the automation industry with a steel grade of S55C. Since linear guide-rails are continuously subjected to repeated stresses, they demand a high degree of hardness and high fatigue life. However, Decarburized steel causes several problems, for example, lowering of hardness and fatigue life, when it is used to manufacture auto parts, or mechanical parts. Therefore, final products of linear guide-rails require no surface decarburization. Deeper decarburization of guide-rails takes longer sandblasting time to remove decarburization, resulting in the increase of customer's costs.

Decarburization is the loss of carbon diffusion from the steel surface, causing a lower carbon concentration than deeper positions beneath the surface. The phenomenon of decarburization usually takes place at temperatures above 700°C, by the following reaction.(1)

$$C_{Fe} + H_2O \Leftrightarrow CO + H_2$$

$$2C_{Fe} + O_2 \Leftrightarrow 2CO$$

$$C_{Fe} + FeO \Leftrightarrow Fe + CO$$

The main mechanism of decarburization is related to diffusion and oxidation of carbon during reheating of the billet. Decarburization is affected by three conditions including furnace temperature, heating time and oxygen content in the heating process of the furnace.

(1) Furnace temperature:
Decarburization reaction begins from 700°C, and the decarburization rate would increase with the increasing temperature gradually until 1250°C.(2)

(2) Heating time:
Longer heating times would make for deeper decarburization.

(3) Oxygen content:
Higher oxygen content accelerates the oxidation reaction.

2. EXPERIMENTAL METHOD

2.1 Production processing

The production process of bar in coil is shown below:

Bloom heating →Bloom scarfing → Bloom rolling to billet → Billet heating → Billet rolling to coil→ Cooling process → Properties test

2.2 Process analysis

According to the metallurgical mechanism of decarburization, the bloom heating and billet heating process are mainly considered, so the key factors include furnace temperature, heating time and oxygen content.

(1) Removal of bloom decarburization:

After reheating of the bloom, the scarfing process removes 2mm thickness from the surface of the bloom, and the decarburized layer can be reduced to ensure as less residual billet decarburization as possible.

(2) Effect of billet heating conditions:

In this experiment by Taguchi method, maximum decarburization depth is arranged as dependent variables, whereas both temperature and heating time are independent variables. Meanwhile, the oxygen content of the furnace is controlled by adjusting the air-fuel ratio, and the correlation between oxygen content and decarburization will be analyzed as well.

3. RESULTS

3.1 Effect of the bloom scarfing process

When the 2mm thickness was removed from the surface of the bloom through the scarfing process, the residual decarburization depth on the billet reduces from 0.52mm to 0mm, as shown in Fig.1.

3.2 Taguchi experiment of the heating process

In this Taguchi experiment, two factors were studied, furnace temperature and heating time, three levels were set, as shown in Table 1. Figure 2~3 show the main factor response diagram, which indicate that there is a higher correlation between the furnace temperature and decarburization, but the heating time has little effect on decarburization.

The diffusion of interstitial carbon in the iron matrix can be interpreted by Arrhenius equation.

$$D = Ae(-Q/RT)$$

Where D is the diffusion rate. A is the Arrhenius coefficient. Q is the activation energy. R is the universal gas constant. T is the absolute temperature.

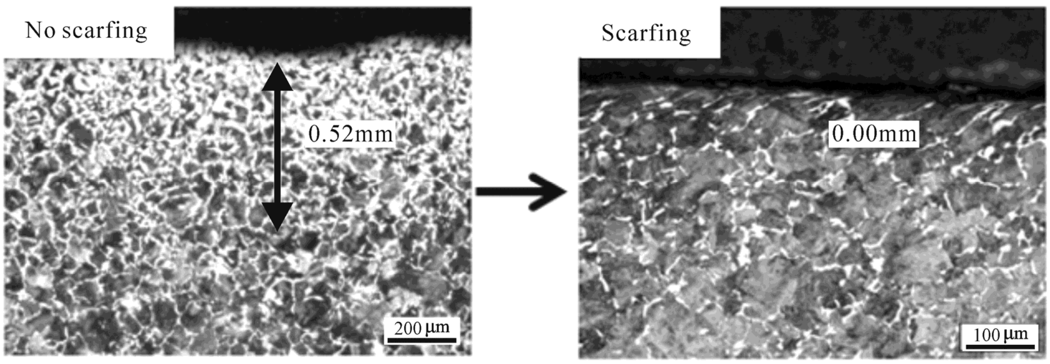

Fig.1. The change of decarburization depth in OM morphology for billet through the scarfing process.

Table 1 Full factor orthogonal table

	Temperature (℃)	Heating time (min)
1	970	100
2	970	120
3	970	200
4	1050	100
5	1050	120
6	1050	200
7	1150	100
8	1150	120
9	1150	200

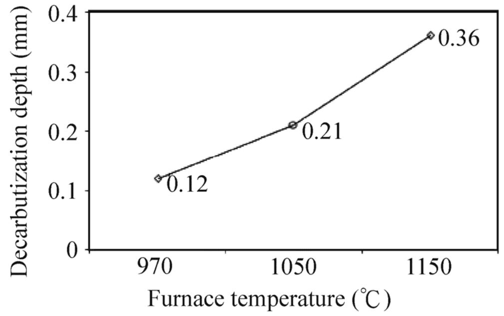

Fig.2. Main factor response diagram of decarburization depth and furnace temperature.

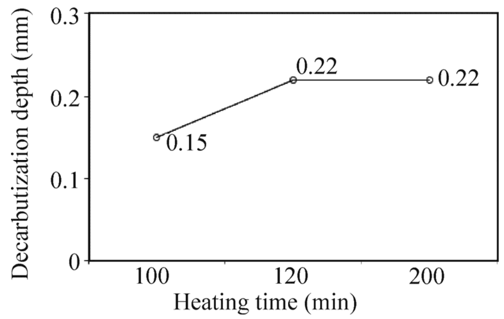

Fig.3. Main factor response diagram of decarburization depth and heating time.

The diffusion rate denoted by ΔC / t, which is proportional to the concentration difference ΔC and is inversely proportional to time t. Thus, the derivation can be simplified as Q = T × ln (t). The activation energy required for decarburization is mainly affected by T × ln (t), and is positively correlated to the decarburization depth, as shown in Fig.4.

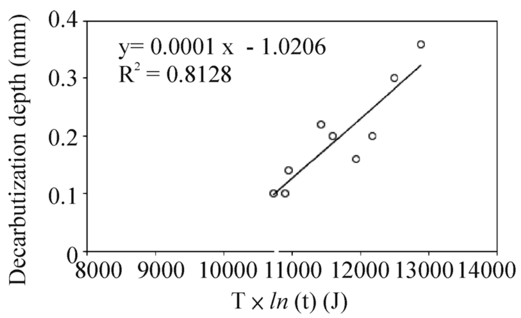

Fig.4. The regression analysis of decarburization depth and T*ln(t).

Through big data analysis, it also shows the relationship of decarburization depth between furnace temperature and heating time, as shown in Fig.5. When the furnace temperature is higher than 1050°C, and the heating time is more than 120 minutes, the decarburization depth > 0.2mm increases from 7% to 47%. The lower furnace temperature and the shorter heating time decrease the driving force of decarburization and the amount of decarburization depth > 0.2mm. This also coincides with the Arrhenius equation.

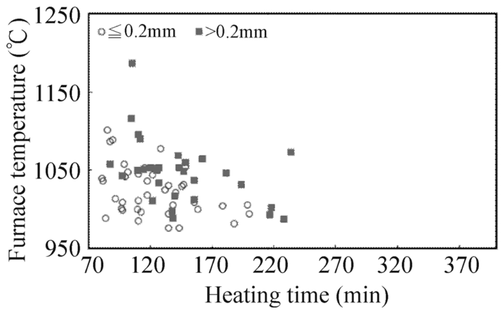

Fig.5. Scatter plot of furnace temperature and heating time for decarburization depth.

According to the above conclusions, some modifications were made, including decreasing furnace temperature from 1050°C to 970°C, optimizing the scheduling plan for stabilizing the furnace temperature to meet the low temperature rolling process.

3.3 Effect of oxygen content

The oxygen mainly comes from the combustion air flow. Figure 6 shows the relationship between oxygen content and decarburization by adjusting air-fuel ratio. The decarburization depth is highly correlative to oxygen content and the R^2 reaches 0.93. This indicates the deeper decarburization depth is as a result of the higher oxygen content.

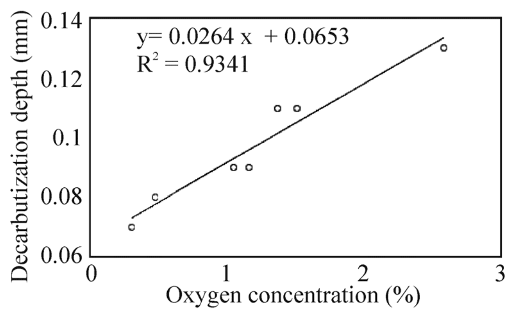

Fig.6. The regression analysis of decarburization depth and oxygen content.

According to the above conclusions, an appropriate air-fuel ratio was optimized to obtain as low as possible oxygen content.

4. CONCLUSIONS

In this study, the key factors of process, furnace temperature, heating time, furnace atmosphere and oxygen content. Hence, a less decarburization depth of S55C for linear guide-rails were achieved by applying a bloom scarfing process and appropriate billet heating process. More specific effects of these factors are compared and identified, which indicates decreasing furnace temperature from 1050°C to 970°C, optimizing the scheduling plan for stabilizing the furnace temperature to meet the low temperature rolling process, and low air-fuel ratio. Through these improvements, the accepted decarburization rate increased from 72% to 99.86% and thus obtained annual benefits of 10.72 million NT dollars. In addition, customers can consequently benefit from reducing the sandblasting process and save 43.6 million NT dollars per year.

REFERENCES

1. Sangwoo Choi: "Optimization of Microstructure and Properties of High Strength Spring Steel", PH.D. thesis, 2011, pp. 139-161.
2. 徐烈山：”加熱過程中降低脫碳率的主要途徑”，Industrial Furnace, vol. 26, no.5, 2004。 □