Prevention of Ferrite Decarburization of Spring Steel SAE 9254 During Wire Rod Rolling Process

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SAE 9254 suspension spring steel is widely applied in the automobile industry. As a part of shock absorbing component, the function of spring requires high hardness and fatigue endurance. It not only needs to endure continuous vibrations of the whole car weight during travel but also maintain high tensile strength and resistance for supporting huge external compression. In order to meet the above mechanical properties, it is normally designed with a medium carbon high silicon composition. However, silicon is the stable element of ferrite, therefore when the rolling temperature of high-silicon steel falls into the ferrite precipitation temperature, a surface area with a low carbon concentration would easily become ferrite decarburization (DM-F). When DM-F occurs, it'll decrease strength leading to poor fatigue life of the steel. Therefore, during the process of wire rod rolling and cooling, the process should be carefully controlled. Through Gleeble simulation, this sensitive temperature region is precisely analyzed. We adjust the stelmor process to avoid the ferrite precipitation as well as keeping the same microstructure and mechanically property of the matrix. After applying the new process, DM-F was effectively improved which can satisfy the customer requirement.

Keywords: High-Silicon Spring Steel, Ferrite Decarburization, Gleeble Simulation, Stelmor Process

1. INTRODUCTION

SAE 9254 high-silicon steel with high tensile strength (1000MPa) which is used in the suspension spring industry. According to the size of the wire rod diameter, φ13mm or less is mostly used for motorcycles, φ13~18mm is used for automobiles. As a part of the shock absorber, the main purpose is to ease the vibration caused by the vehicle during travel as well as resist huge external compression. Therefore, it requires high hardness and fatigue endurance.

Ferrite decarburization (DM-F), as shown in Fig.1, which has caused this zone to lose most of its carbon content, so the strength of the surface will be severely reduced and the hardness and fatigue endurance will also decrease. Thus, we should avoid the generation of ferrite decarburization during the rolling process.

Fig.1. Ferrite decarburization in OM morphology

2. EXPERIMENTAL METHOD

2.1 *Mechanism of Metallurgy*

According to literature*1, the forming mechanism of ferrite decarburization in high silicon spring steel varies with different temperature ranges. Mainly based on the two points as $Ar_3(C=0\%)$ and $Ar_3(C=C0)$, which divide the phase diagram into three zones (a)~(c), shown in Fig.2. The decarburization mechanism of each zone are explained as follows:

(a) The area above Ar_3 point (C=0.0wt%). At this time, there is no ferrite transformation, the decarburization in this temperature zone is diffusion controlled.
(b) The area between point Ar_3 (C=0.0wt%) and Ar_3 (C=C0). Affected by surface decarburization, ferrite begins to precipitate, and decarburization is controlled by partial phase transformation.
(c) This zone is below the temperature of Ar_3 point (C=C0). Decarburization in the two-phase region is controlled by phase transformation, and ferrite precipitates quickly.

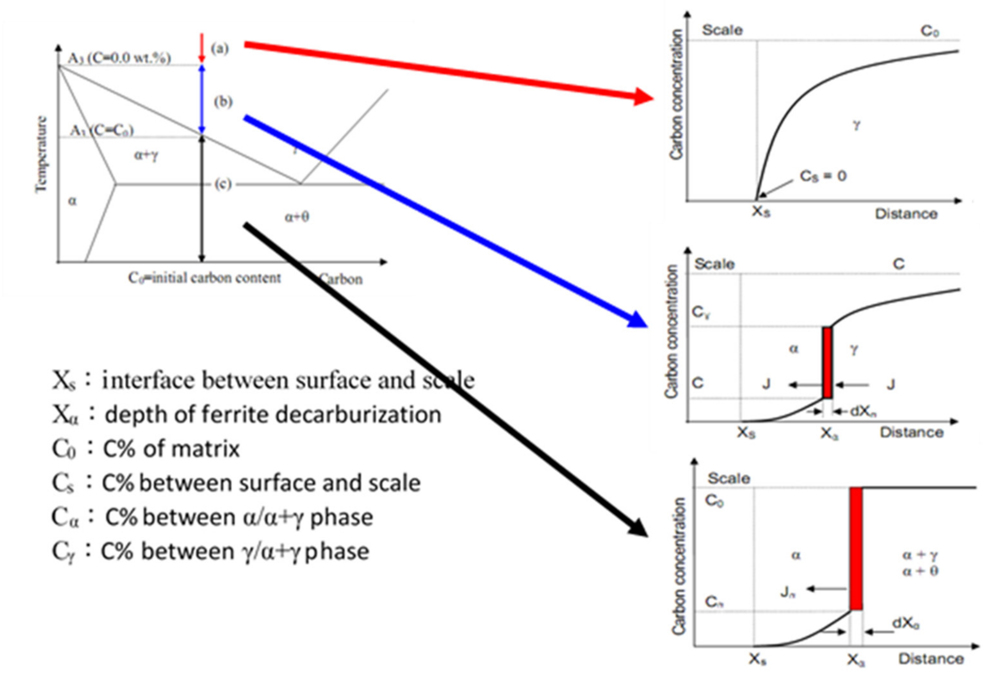

Fig.2. Decarburization mechanism of high-silicon spring steel

Since silicon is the stable element of ferrite, for high-silicon steel, when the rolling temperature falls into the ferrite precipitation temperature, surface area with low carbon concentration would easily result in ferrite decarburization (DM-F).

To verify the relationship between DM-F and rolling temperature, we used a Gleeble simulation at different temperatures and observed changes of the microstructure. Eventually, this sensitive temperature region is precisely analyzed.

2.2 Process Analysis

The cooling system of the Bar#2 mill after rolling is shown in Fig.3. The controllable factors of the cooling rate are listed as follows:

(1) Water box: By adjusting the volume of water to control the temperature after finishing rolling.

(2) Cooling fan: There is a total of eight zones, each zone is equipped with cooling fans, which can control the cooling rate by adjusting fan rotation speed.

(3) Cover: Each zone is equipped with an insulation cover, which can be opened or closed if necessary.

(4) Roller speed: By adjusting the roller speed to control the stacking density of the coil and the time it travels through the stelmor cooling conveyor.

As we know there is a difference between the hot and cool zone of the same coil ring when the coil is laying on the stelmor cooling conveyor. Coil rings at the two sides stack denser and remain relatively hotter, on the contrary, the rings in the middle zone stack less dense and become relatively cooler, as shown in Fig.4. Because the coil rings at the two sides cool down slowly, their temperature falls into DM-F sensitive temperature region and will remain there for longer. To verify this viewpoint, we took samples from the cool and hot zones for test. The experimental result shows that the DM-F is 0 mm in the cool zone and 0.02~0.03mm in the hot zone, so the stelmor cooling process needs to be appropriately adjusted.

3. RESULTS AND DISCUSSION

3.1 Process adjustment

To avoid ferrite precipitation while maintaining the same mechanical properties for easy drawing, we made suitable improvements, as follows: lowering of the original laying temperature of the coil and enhance fan rotation speed to obtain the most appropriate cooling rate.

3.1.1 Lower the original laying temperature of the coil

As mentioned before, when the coil laying temperature falls into the DM-F sensitive temperature region, zones (b) and (c) would precipitate ferrite quickly. To avoid this phenomenon, we decrease the laying temperature of the coil. Therefore, the time of the laying temperature falling into the DM-F sensitive temperature region will be reduced. On the other hand, to avoid the formation of bainite forms during the cooling process as

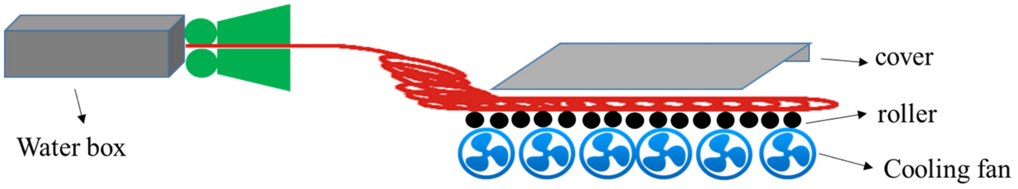

Fig.3. Cooling system after rolling

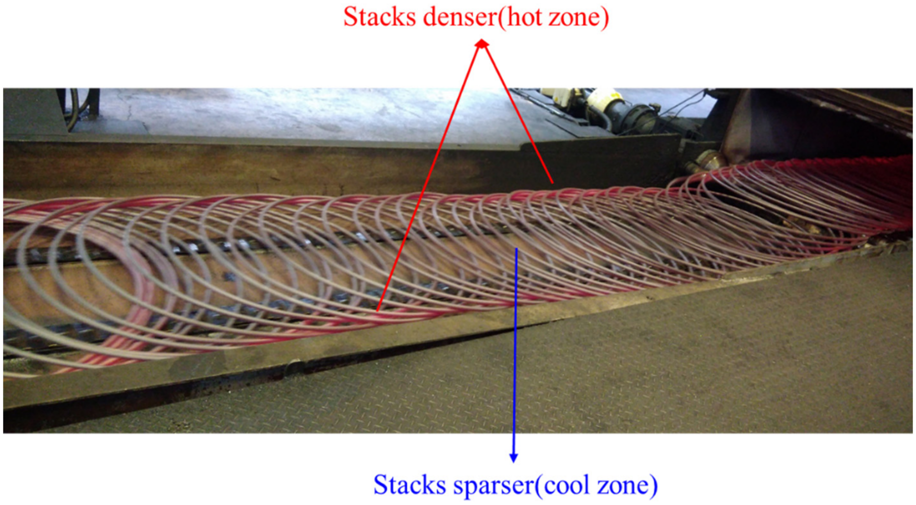

Fig.4. Hot and cool zone of coil rings on stelmor cooling conveyor

well as wire rod not being easy to convolute to coil, the laying temperature should not be too low. Consequently, the laying temperature will still fall in to zone (c). To solve this problem, the stelmor cooling rate must be further increased.

3.1.2 Fan speed adjustment

To compromise tensile strength and DM-F, the Taguchi experiment method was introduced to find the most suitable parameters. Depth of DM-F and tensile strength are arranged as dependent variables, and we chose two of the most powerful fans which were referred to as front and end zone fan, arranged as independent variables. Two factors of front and end zone fan speed with four levels were set, as shown in Table1.

The analysis of main effects plots of DM-F and TS with front and end zone fan speed are shown in Fig.5 and 6. The results show that DM-F can be decreased by enhancemeant of both front and end fan speed. This is due to the faster cooling rate, the time of laying temperature falling into zone (c) will effectively be shortened. Therefore, the chance of ferrite precipitation will almost be zero.

However, tensile strength will increase simultaneously with fan speed. Besides, we observed that both DM-F and tensile strength are obviously affected by the fan speed of front zone than end zone. Taking both DM-F and tensile strength in to consideration, we should modestly enhance fan speed to improve DM-F and keep tensile strength from being too high so to avoid it being a disadvantage in the following drawing process.

3.2 Improvement check

After applying the new process, we checked the laying temperature and obviously it was lower than that of the original process as shown in table 2. Therefore, the time the laying temperature falls into the DM-F sensitive temperature region can be effectively avoided with the following cooling process.

The depth of DM-F of the samples from hot zone and cool zone are measured both 0 mm. The tensile strength was also analyzed as listed in Table 3. We further observed that microstructures consisted of pearlite and ferrite without bainite as usual. We can still maintain a relatively soft and easy to draw microstructure after the improvements. Furthermore, tensile strength still meets customer requirements as well. After applying the new process in the following mass production, the depth of DM-F were all found to be 0mm, disqualification of DM-F reduced from 4.1% to 0%. Therefore, resulting in a cost saving benefit of 0.85 million NT dollars annually.

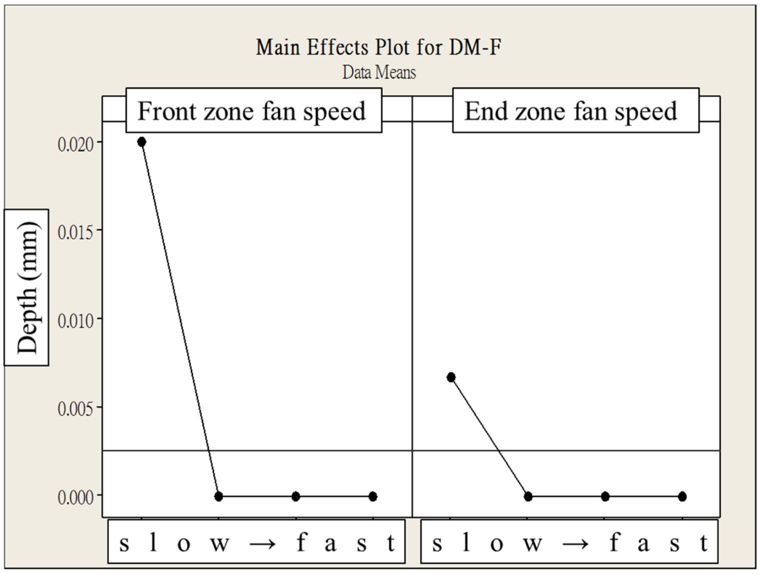

Fig.5. Main effect plot for DM-F with front and end zone fan speed

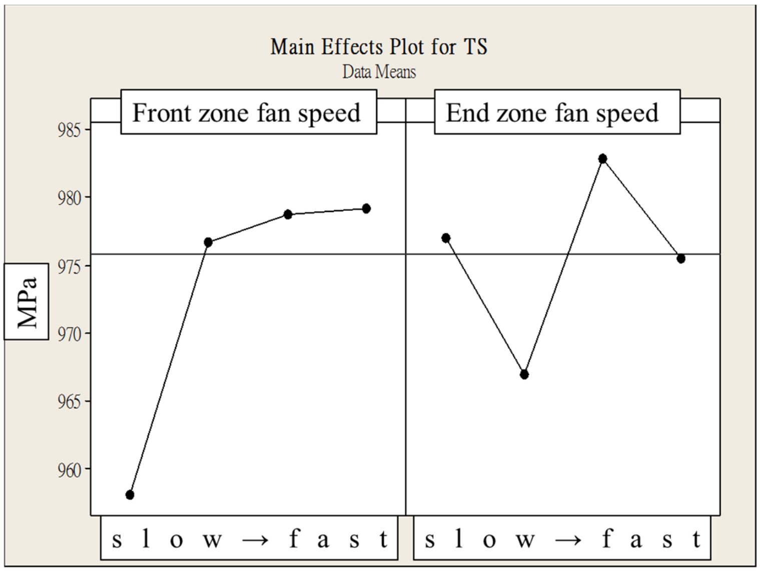

Fig.6. Main effect plot for tensile strength with front and end zone fan speed

Table 1 Partial factor orthogonal table

Process number	Front Zone fan speed	End Zone fan speed
1	Very fast	Very fast
2	Very fast	Very slow
3	Fast	Fast
4	Fast	Slow
5	Fast	Very slow
6	Slow	Fast
7	Slow	Slow
8	Very slow	Very slow

Table 2 Laying temperature of original and improved process

Process	Laying temperature (°C) (cool ~ hot zone)
Original process	730~770
Improved process	700~750

Table 3 Tensile strength of original and improved process

Process	TS(MPa)
Original process	958
Improved process	960

4. CONCLUSIONS

The main factor of forming DM-F is affected by the cooling process of coil ring after rolling. Through controlling the parameters of the Stelmor cooling conveyor as follows : (1) Lower the original laying temperature, (2) enhance fan rotation speed, DM-F of high-silicon spring steel is effectively improved. Besides, microstructure and tensile strength remains consistent with old and new process. Customers are satisfied with improvement by new process.

REFERENCES

1. Sangwoo CHOI，POSCO，”An Approach to Predict the Depth of the Decarburized Ferrite Layer of Spring Steel Based on Measured Temperature History of Material during Cooling”, 2014. □