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Development of Time-Shortened Spheroidization Process to Conserve Energy and Decrease Carbon Emissions

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Spheroidized annealing requires a prolonged period of high-temperature heat treatment, consuming a significant amount of time and energy, which leads to decreased production efficiency and increased carbon emissions. Hence, this study explores methods for shortening the annealing time. The spheroidization time is mainly influenced by the hot-rolled structure and the annealing parameters. Experiments have confirmed that fine-grained pearlite is the most suitable for developing a time-shortened spheroidization process. The plan is to reduce the rolling temperature and control the cooling speed to produce fine-grained pearlite. The research employs the Taguchi method for experimental design and analysis to identify the most suitable rolling and annealing parameters. The new process results in a 10% reduction in spheroidization time while maintaining the original spheroidization quality. It is estimated to decrease carbon emissions by 87 tons per year.

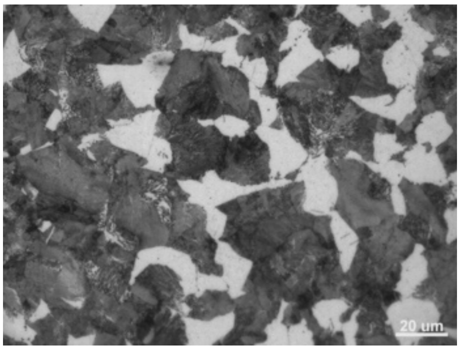
Keywords: Time-shortened spheroidization process, Carbon reduction

1. INTRODUCTION

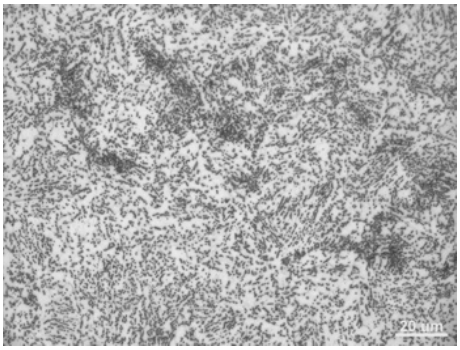
Spheroidization aims to improve the formability of steel and reduce the deformation resistance during cold working, making it widely employed in the manufacturing of high-strength and high-toughness hand tools, fasteners, etc.

Wire coils usually use the intercritical process for spheroidized annealing, which heats the steel to a constant temperature between A_{C1} and A_{C3}, and promotes the dissolution of carbides. When the subsequent slow-cooling or holding below A_{C1}, driven by the reduction of interfacial energy of ferrite and cementite, the precipitated carbides tend to transform into a spheroidized morphology as shown in Figure 1. However, spheroidized annealing requires a prolonged period of high-temperature heat treatment, consuming a significant amount of time and energy, leading to decreased production efficiency and increased carbon emissions.

As global warming contributes to abnormal climate patterns, concerns over greenhouse gas emissions are escalating. Energy conservation and carbon reduction have become key focal areas in recent years. Hence, this study delves into methods for shortening the annealing



(a)



(b)

Fig.1. The microstructure of low alloy steel (a) Before spheroidization: ferrite and pearlite (b) After spheroidization: granular carbides.

time.

To shorten the annealing time, 50BV30 steel was used to test the original spheroidization mode (Mode A) and two time-shortening spheroidization modes (Mode B and C), as shown in Figure 2. The spheroidization results are presented in Table 1.

In Mode B, the annealing time is shortened by 1 hour compared to Mode A, resulting in a worse spheroidization rate and hardness. The microstructure shows residual pearlite, indicating insufficient annealing time or temperature in Mode B.

To improve the residual pearlite, in mode C, in addition to shortening the annealing time by 1 hour, the spheroidization temperature was increased by 10°C. As a result, hardness improved, but the spheroidization rate remained high, resulting in a structure showing regenerated pearlite, which was caused by the high spheroidization temperature. These experiments indicate that directly reducing the time under current raw materials and equipment conditions would degrade the spheroidized quality, thereby necessitating an alternative approach.

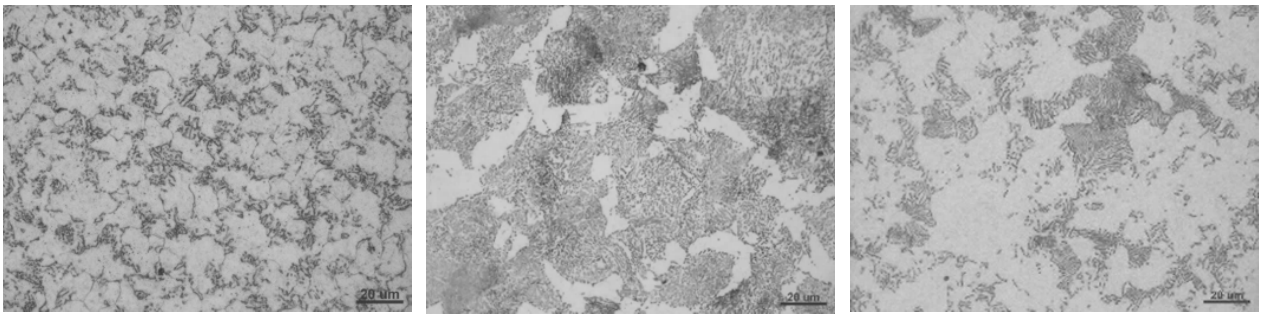
Based on document[1], reducing the rolling temperature and increasing the cooling rate can slow down the recrystallization rate and produce a fine-grained structure. The finer the grains, the more grain boundaries there are, which can provide more nucleation points, leading to an accelerated austenitization rate and precipitation of carbides, benefiting rapid spheroidization.

In addition, the hot-rolled structure may affect the spheroidization results[2]. At room temperature, common structures in steel include coarse pearlite, fine pearlite, bainite, and martensite. Pearlite exhibits a laminar structure of fine carbides in ferrite and typically requires more time for carbide spheroidization compared to the latter two, but it tends to have lower hardness.

2. EXPERIMENTAL METHOD

2.1 Verification of Metallurgical Mechanisms

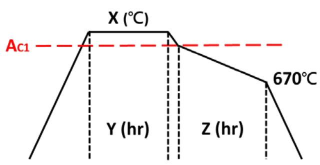
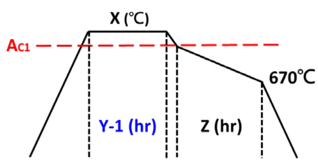
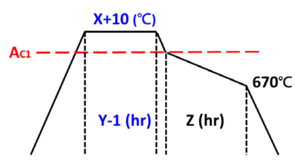
To verify the effect of rolling temperature on grain size, the Gleeble thermal mechanical simulators to study the microstructure differences of SCM440 steel at various rolling temperatures. Figure 3 illustrates the thermal process, where specimens were heated to 1050°C and held for 120 seconds to promote austenite phase transformation, followed by cooling to specific rolling temperatures (900°C, 800°C, and 750°C), holding for 3 seconds, applying 50% strain, and finally slow cooling at 0.5°C/s. The microstructures of the three experimental parameters are shown in Figure 4, revealing that lower rolling temperatures result in finer grains and an increasing proportion of pearlite, confirming that reducing the rolling temperature facilitates the production of fine-grained pearlite.



(a) (b) (c)

Fig.2. The microstructure acquired from different spheroidized annealing pattern . **(a)** Pattern A **(b)** Pattern B **(c)** Pattern C.

Table 1 The spheroidization results of three patterns.

Pattern	A		B		C	
						
Quality Index	Spheroidiza-tion rate	hardness (HRB)	Spheroidiza-tion rate	hardness (HRB)	Spheroidiza-tion rate	hardness (HRB)
Values	3	73.7	5	81.9	4	70

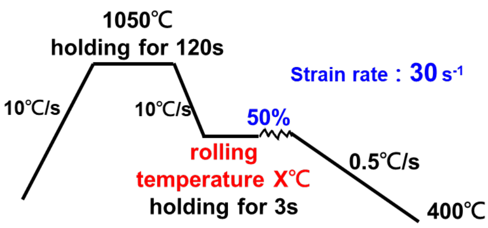
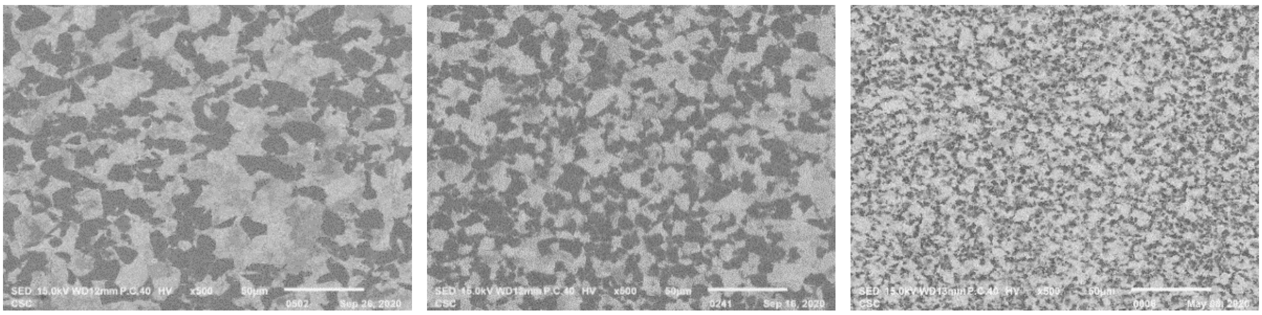


Fig.3. Gleeble experimental thermal process.

To clarify the optimal hot-rolled structure, experiments were conducted in the experimental furnace with 50BV30 steel using different heat treatment and cooling parameters. The steel was heated to 900°C and held for 15 minutes to achieve homogeneous austenitization. Subsequently, it was cooled using water quenching, salt bath, and furnace cooling methods to produce martensite, bainite, fine pearlite, and coarse pearlite structures (fig.5). Then, annealing for spheroidization was conducted at an average temperature of 750°C for 1 hour. As shown in Table 2, under short-term annealing, only fine pearlite exhibited a superior spheroidization rate and hardness, making it the most ideal structure.

2.2 Experimental Design

After confirming that rolling temperature and cooling rate are critical factors influencing spheroidization performance, a 3-factor 2-level Taguchi experiment was designed to obtain the optimal process parameters, as shown in Table 3. Level 2 represents the original process parameters, while Level 1 involves low-temperature



(a) (b) (c)

Fig.4. The microstructure varies with different rolling temperatures (a) X=900℃ (b) X=800℃ (c) X=750℃.

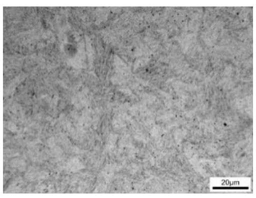
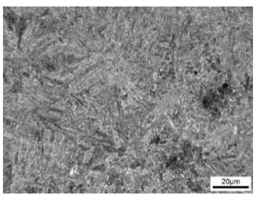
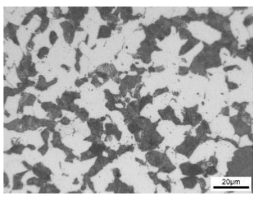
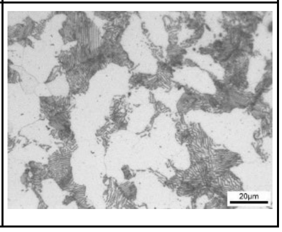
Cooling Method	Quenching	salt bath at 410°C for 60 minutes	hold at 600°C for 60 minutes	hold at 700°C for 60 minutes
Microstructural	Martensite	Bainite	Fine Pearlite	Coarse Pearlite
Metallography				

Fig.5. Produced four types of microstructures through different heat treatment processes.

Table 2 Spheroidization results of different microstructures.

Microstructural		Martensite	Bainite	Fine Pearlite	Coarse Pearlite
Before annealing	Hardness (HRB)	>109	102.5	90.7	78.7
After annealing	Hardness (HRB)	83.8	82.6	74.9	70.7
	Spheroidization rate	1	1.5	2	4

Table 3 Factor and level comparison table.

Factor	Process Parameters	Level 1	Level 2
A	rolling temperature(°C)	X-60	X
B	colling parameters	slow cooling	rapid cooling
C	conveyor speeds (min)	Y	Y-6

rolling parameters combined with different cooling rates and conveyor speeds. Then, based on the Taguchi method, an L4 orthogonal array was used to conduct experiments with 50BV30 steel, as shown in Table 4. With spheroidization rate and hardness as the quality characteristics and aiming for lower values, the main effects analysis identified the optimal parameters as 'X-60+slow cooling+Y'.

3. RESULTS AND DISCUSSION

The optimal parameters obtained from the Taguchi experiment were applied in the production of 50BV30 coils. Subsequently, three different time-shortened spheroidization modes were applied, as shown in Figure 6.

Table 5 shows the spheroidization results. Modes B and C increased the soaking temperature by 5°C and shortened the process by 4.5 to 5 hours, resulting in worse spheroidization rates and hardness compared to Mode A. Mode A, which reduced the slow cooling time by 2 hours compared to the original mode, achieved spheroidization rates and hardness levels comparable to the original process. Microscopic observations, as shown in Figure 7, revealed a uniform distribution of spheroidized carbides with no residual or regenerated

Table 4 L4 experimental orthogonal array and results.

Number of Experiments	Factor / Level			After spheroidizing treatment	
	A	B	C	Spheroidization Rate	Hardness (HRB)
1	1	1	1	2.0	70.3
2	1	2	2	2.1	71.1
3	2	1	2	2.6	70.4
4	2	2	1	2.5	71.5

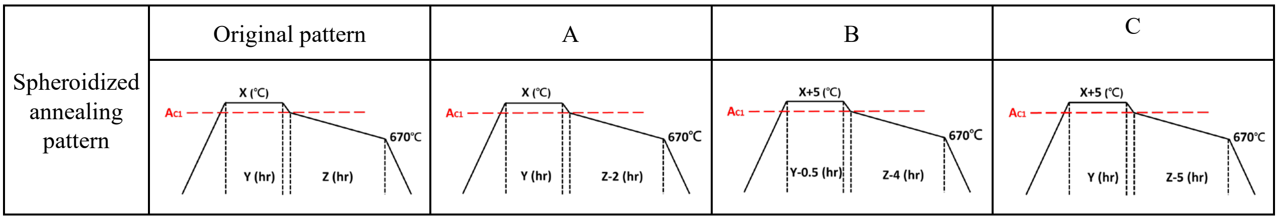
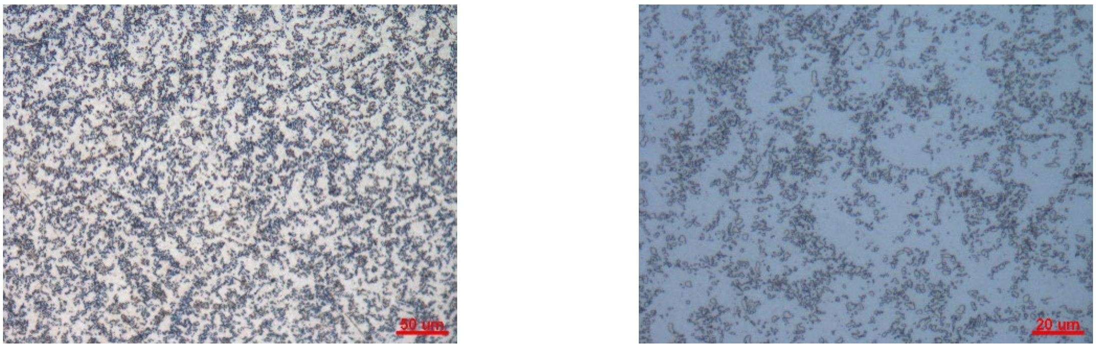


Fig.6. Spheroidized annealing patterns.

Table 5 Spheroidization results of different processes.

Spheroidized Mode	Time-shortened	Spheroidization Rate	Hardness (HRB)
Original	-	2.2	72.1
A	2 hours	2	72.3
B	4.5 hours	2.3	74.9
C	5 hours	2.5	76.4



(a) (b)

Fig.7. The microstructure acquired from the low-temperature rolling process combined with the time-shortened spheroidization process (a) magnification 200 and (b) magnification 500.

Table 6 Spheroidization quality by using the new process.

Steel grade	Spheroidized Mode	Time-shortened	Spheroidization Rate		Hardness (HRB)	
			average	standard deviation	average	standard deviation
50BV30	New	2hours	2.2	0.5	71.5	1.7
	Original	-	2.1	0.4	72.2	1.7
SCM435	New	2hours	1.8	0.5	80.7	2.4
	Original	-	1.7	0.4	80.4	2.1

pearlite. Therefore, Mode A was selected for mass production. Since the improvement effect was assured, the novel technology was facilitated in another alloy steel SCM435.

After six months of actual mass production, the statistical spheroidization quality results are shown in Table 6. After applying a low-temperature rolling process combined with a time-shortened spheroidization process to SCM435 and 50BV30 steels, the average spheroidization rate and hardness, as well as their standard deviations, remain comparable to the original levels. This new process successfully shortens the spheroidization time without affecting the quality of spheroidization.

Using the time-shortened spheroidization method reduces process time by approximately 10%, resulting in lower COG, nitrogen usage, and electricity consumption. It is estimated to decrease carbon emissions by 87 tons per year.

4. CONCLUSIONS

In response to the company's energy-saving and carbon reduction policies, research focused on optimizing hot-rolled processes to achieve the goal of shortening spheroidization time while maintaining quality. This study emphasizes investigating the impact of hot-rolled parameters on spheroidization performance. Experimental verification shows that low-temperature rolling can refine grain size, facilitating the spheroidization of carbides. Moreover, appropriately slowing down the cooling rate can produce a finer pearlite structure that is easier to spheroidize.

Using Taguchi experiments to evaluate the optimal rolling parameters, coupled with the new process mode, each batch can be shortened by 2 hours without compromising spheroidization quality. The implementation of this approach in factory-scale production has shown promising results, and there are plans to expand its application to other steel grades to enhance carbon emission reduction benefits.

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