China Steel Technical Report, No. 38, pp.32 —36, (2025)

The Development of Energy-Saving High-Strength EN S450GD Structural Steel Product

CHUN-YUAN HUANG*, TSUNG-EN YANG* and HUAN-ZHANG CHEN**

**Metallurgical Department*
***Rolling Mill Department*
China Steel Corporation

Due to high-strength requirements, the EN G450GD structural steel product primarily obtains its mechanical properties by relying on the addition of alloying elements, such as C, Mn, Nb, Ti, and V, which contribute via solid-solution strengthening, grain-refinement strengthening, and precipitation-strengthening mechanisms. However, the addition of alloying elements increases steelmaking cost and raises the recrystallization temperature, leading to greater energy consumption and carbon emissions. Therefore, to achieve multiple goals–including energy saving, alloy reduction, and robust quality–CSC has developed an advanced production method that achieves both high strength and superior surface quality without adding excessive alloy addition or elevated annealing temperatures, by precisely controlling the microstructure and degree of recrystallization of the material.

Keywords: Structural steel, High strength, Energy saving

1. INTRODUCTION

Galvanized Steel is widely used in many different industries, including the automobile, construction, and home appliance sectors, due to its excellent corrosion resistance. Recently, driven by trends in energy saving and environmental protection, the demand for higher-strength, lighter-weight materials with superior anti-corrosion properties, such as EN S450GD, has been gradually increasing.

Conventionally, designing a material to achieve the high strength of the EN S450GD product requires the combination of multiple strengthening mechanisms, including solid-solution strengthening, fine-grain strengthening, and precipitation strengthening, which leads to high fuel consumption and increased alloy cost. Furthermore, excessive alloy content can also deteriorate the weldability and coating adhesion properties of the material.

Therefore, to achieve higher strength by using other strengthening mechanisms, such as deformation strengthening, represents a new and advanced design approach. By precisely controlling the microstructure of the material, it is possible to maintain an incomplete recrystallization state and enhance strength. Using this approach allows high strength to be achieved without excessive alloy addition, while reducing the annealing temperature, improving welding performance, and surface quality.

2. EXPERIMENTAL METHOD

2.1 Chemical Composition Design

Table 1 shows the chemical composition of two types of steel. Steel A represents a conventional chemical composition design for the EN S450GD product. The composition of Steel A includes a significant amount of [C] and [Mn] to maximize the solid-solution strengthening effect, and also contains [Nb], which is the primary contributor to the precipitation strengthening mechanism.

Steel B, on the other hand, is designed for an energy-saving EN S450GD product. In addition to reducing the [C] and [Mn] content, which aims to enhance weldability and adhesion properties and to save alloy costs, [Nb] is replaced with other elements to lower the recrystallization temperature and reduce fuel consumption.

2.2. Cold Rolling Reduction Rate and Annealing Temperature

Steel was produced on a commercial-mass production line, including the Tandem mill and CGL line. A schematic illustration of the production procedure is shown in Figure 1. The general reduction rate and annealing temperature for Steel A are denoted as R1 and SS1, respectively.

Table 1 Chemical composition of experimental steel.

	C	Mn	Others
Steel A	0.08–0.12%	1.2–2.0%	Nb, V
Steel B	0.04–0.08%	0.8–1.2%	Others

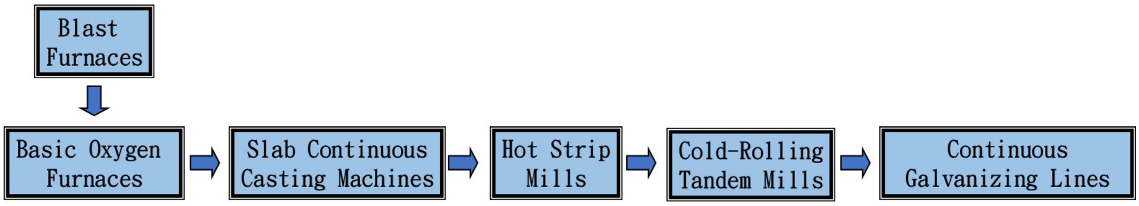

Fig.1. Production flow of CSC CGL product.

For steel B, three annealing temperature (SS1~SS3, SS1>SS2>SS3) and two reduction rate (R1~R2, R1>R2) were designed to investigate their effects.

2.3. Mechanical Characterizations and Microstructure Analysis

After the galvanizing process, mechanical test samples and metallographic samples were taken from the steel sheet. The mechanical samples were cut parallel to the rolling direction and processed into tensile specimens according to the specifications of the EN sheet type. Tensile tests were conducted to measure the mechanical properties.

Metallographic samples were etched before and subsequently observed under an optical microscope.

2.4. Surface Quality

This specification applies to structural steel use. Since the chemical composition of Steel B differs significantly from that of traditional Steel A, it may affect the surface quality of the steel strip. Therefore, visual inspection and ASIS (Automatic Surface Inspection System) were used to evaluate whether the material meets application requirements.

3. RESULT AND DISCUSSION

3.1 Calculation of Theoretical Strength

Steel B, compared to Steel A, significantly reduces the content of various alloying elements, which inevitably decreases the strengthening effect of the steel. Before commencing production on the manufacturing line, theoretical calculations were used to estimate the possible yield strength (YS) range for both steels. These calculations consider the solid-solution strengthening, grain-refining strengthening, and precipitation-strengthening mechanisms. The results are summarized in Table 2.

The theoretical YS range of Steel A is 476–494MPa, which meets the requirement for the EN S450GD product. In contrast, the theoretical YS range of Steel B is 423–446MPa, which falls short of the requirement. This indicates the need to introduce alternative strengthening mechanisms, such as deformation strengthening, for Steel B to enhance its properties and meet the development requirements.

3.2 Mechanical Properties

Table 3 presents the mechanical properties for different experimental conditions. Although Steel B was produced using the same reduction rate (R1) and annealing temperature (SS1) as Steel A, its strength values are 50–70 MPa lower, with YS/TS = 431MPa /522MPa, close to the median of the theoretical strength calculated above.

When keeping the reduction rate at R1 but varying

Table 2 Theoretical strength of design composition*1.

(MPa)	YS	TS
Steel A	476–494	577–611
Steel B	423–446	488–553
EN S450GD Spec	450 min	510 min

*Assumed average diameter of the precipitate phase 0.01μm and the average grain size 6–8μm. The volume fraction of precipitation is the same for both steels.

Table 3 Mechanical Properties Results.

Composition	Tandem Mill Reduction Rate (%)	CGL Annealing Temperature (℃)	YS (MPa)	TS (MPa)	EL (%)
Steel A	R1	SS1	488	599	20.9
Steel B	R1	SS1	431	522	24.2
		SS2	445	520	24.5
		SS3	493	577	20.1
	R2	SS1	449	567	20.6
		SS2	495	592	20.2
EN S450GD Spec			450 min	510 min	14 min

the annealing temperature (SS1→SS2→SS3), the YS of Steel B increased from 431 MPa → 445 MPa → 493MPa, reaching the specification requirement under the SS3 condition.

Comparing Steel B produced at the same annealing temperature but with different reduction rates (R1, R2), it becomes evident that the lower reduction rate (R2) consistently yielded higher strength. The phenomenon can be explained by the observed microstructure.

3.3 Microstructure

Figure 2 shows the microstructure of Steel A (R1, SS1). Which exhibits full recrystallization under the experimental conditions. The structure consists of ferrite and dispersed carbide.

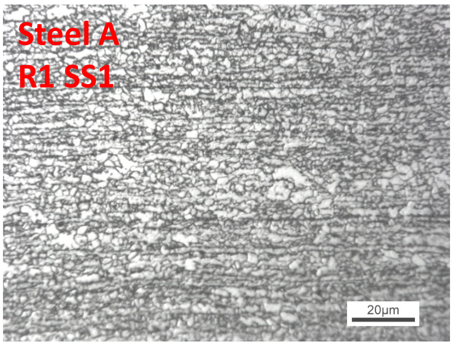

Fig.2. Microstructure of Steel A (R1, SS1).

Figure 3 shows the microstructure of Steel B under various experimental conditions. At a constant reduction rate (R1), shown on the left side of Figure 3, the microstructure gradually transforms from fully recrystallized to incompletely recrystallized as the annealing temperature decreases. (SS1→SS2→SS3). For Steel B (R1, SS3), the microstructure is dominated by work-hardened grains aligned with the rolling direction. The high dislocation density of the microstructure enhances the deformation strengthening effect and increases the material's strength.

Comparing the microstructure of Steel B between (R1, SS2) and (R2, SS2), it could be concluded that the higher reduction rate (R1) promotes recrystallization. Therefore, a higher reduction rate needs to be paired with a lower annealing temperature to achieve the same state and mechanical properties as the low reduction rate sample.

3.4 Surface Quality

All Steel B coils exhibited only sporadic steelmaking linear steelmaking defects and are all suitable for structural steel applications. Compared with traditional Steel A, the carbon content of Steel B is only 0.04–0.08%, avoiding the peritectic composition range. Traditional Steel A coils had a steelmaking defect rejection rate of about 2% at CSC, whereas trial Steel B coils had 0% rejection. Therefore, it is believed that Steel B also has superior surface quality.

3.5 Cost-Effectiveness Evaluation

The goals of developing the energy-saving, high-strength EN S450GD structural GI product include minimizing alloy additions, reducing fuel consumption, and improving application properties. Table 4 summarizes the benefits of the new product compared to the traditional design. The energy-saving EN S450GD product reduces alloy costs by 13% and carbon emissions by 7%, thereby decreasing the annealing temperatures, and also improves weldability due to reduced carbon equivalent.

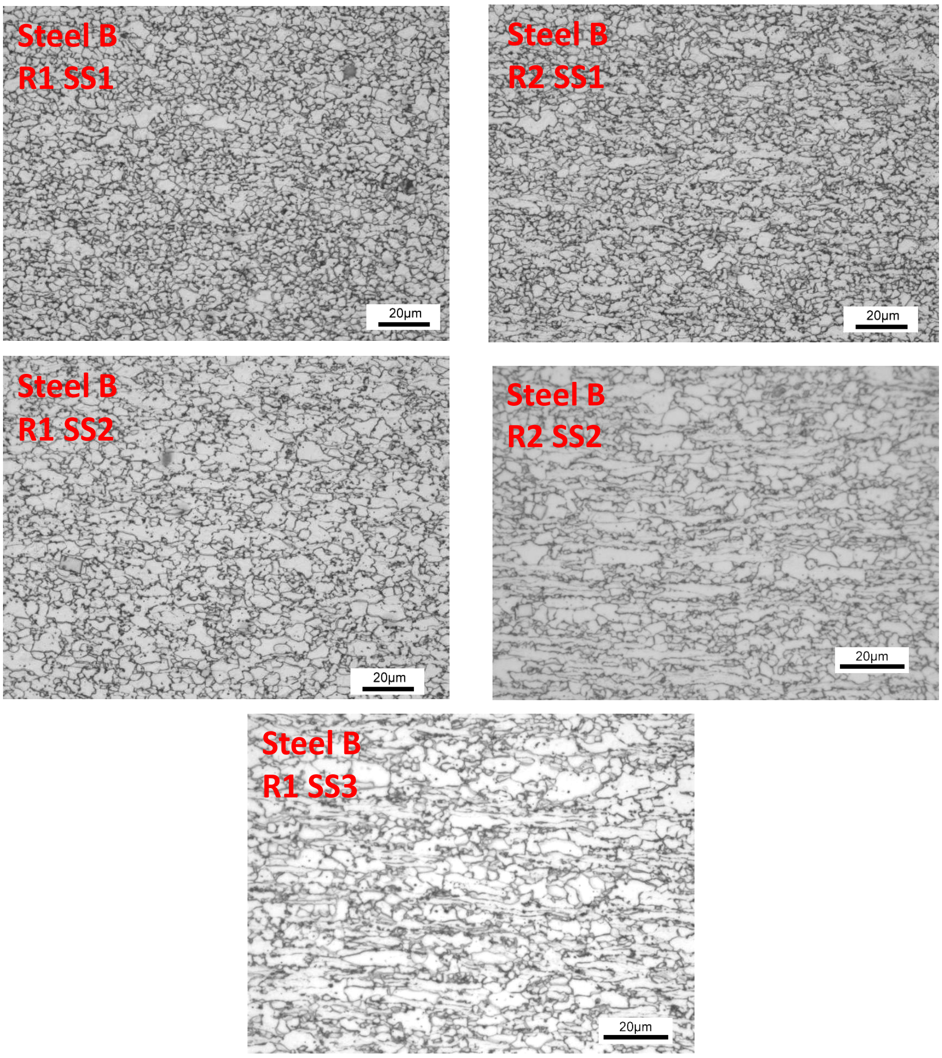

Fig.3. Microstructure of Steel B under Various Experimental Conditions.

Table 4 Evaluation of the benefits of the energy-saving EN S450GD product.

	Alloy Reduction	Carbon Emission	Carbon Equivalent
Traditional Design EN S450GD	Base	Base	0.28–0.45
Energy-saving EN S450GD	-13%	-7%	0.17–0.28

4. CONCLUSIONS

With growing emphasis on energy saving and environmental protection, the demand for high-strength galvanized (GI) products continues to rise. To meet demand for high mechanical properties, steel manufacturers typically increase material strength by adding large amounts of alloy elements. However, excessive alloy content not only increases production costs but also deteriorates key application properties, such as weldability and coating adhesion. Therefore, employing alternative strengthening mechanisms to enhance mechanical properties represents a new approach to designing high-strength structural steel.

China Steel Corporation (CSC) has developed a new chemical composition for the EN S450GD product. Compared with the traditional composition, the new design significantly reduces alloying elements. Strength simulation, which considered solid-solution strengthening, fine-grain strengthening, and precipitation strengthening, indicated that the strength of the new chemical composition alone would be insufficient to meet EN S450GD product requirements. This implies that additional strengthening mechanisms must be introduced to further improve the mechanical properties.

Tensile and microstructure results showed that, under the same manufacturing condition (R1, SS1), the strength of Steel B is about 50–70MPa lower than that of the traditional Steel A, consistent with the simulated median strength under a fully recrystallized state.

The results further demonstrated that a new composition must be paired with an incompletely recrystallized microstructure to achieve the required strength for the EN S450GD product. Furthermore, compared to lower-reduction samples, higher-reduction samples require lower annealing temperature to achieve equivalent states and mechanical properties.

In addition, the new chemical composition adopts a low-carbon design, thereby avoiding the peritectic steel range. This not only provides welding performance but also ensures superior surface quality.

REFERENCES

1. Jiakuan Ren, Zhenyu Liu, Mechanical Properties and Strength Prediction of Ti Microalloyed Low Carbon Steel with Different Ti Content, 2019.
2. Hung-Ping Wang, The Development of GI EN 10346 S350GD Structural Steel, 2019.