Causes of Corner Cracking in Automobile Steel Slab and an Improved Manufacturing Process Technology

HUNG-JU CHANG*, MING-HUNG CHEN* and JHIH-BO GAO**

*Iron & Steel Research & Development Department
**Steelmaking Department
China Steel Corporation

Among the steel grades produced by the vertical bending caster, the rejection rate of Sxx defects in automotive steels is consistently higher than that of other steel grades. The reason is that the composition design of automotive steels makes the slabs particularly prone to corner cracks during solidification and cooling due to peritectic transformation, high manganese content, and the addition of niobium and boron. The mechanism of Sxx defects will be systematically analyzed on how the formation of corner cracks is affected by the high-temperature toughness of steel slabs through precise high-temperature mechanical property measurements. The chamfering mold technology will be applied in actual production to improve the quality of steel slabs produced by the vertical bending caster for automotive steels. The vertical bending caster enables increased yield and reduced costs in the production of automobile steels.

Keywords: Hot-rolled automobile steel, Corner cracking, Chamfered mold

1. INTRODUCTION

The issue of corner cracking in slabs produced by vertical bending casters has been observed to be particularly severe in the second steelmaking plant. These defects not only result in additional costs due to scarfing and corner-chamfering of slabs, but also significantly contribute to the high detection and rejection rates of S02E defects in hot-rolled products. Although significant improvements in corner cracking and S02E rejection rates have been achieved through the optimization of mold cooling water flow, the rejection rate of Sxx defects in high-strength automotive steels has remained the highest among all steel grades, as shown in Figure 1.

The alloy design of high-strength automotive steels typically involves the addition of elements such as high manganese (Mn), niobium (Nb), and boron (B). When the contents of aluminum (Al) and nitrogen (N) are relatively high, precipitates such as NbC, Nb(C, N), VC, AlN, and BN tend to form along the grain boundaries of the primary austenite. These precipitates can exacerbate embrittlement in the third brittle temperature range, thereby increasing the susceptibility of the steel to corner cracking. Due to the high incidence of corner cracking in these steels, current finishing control measures

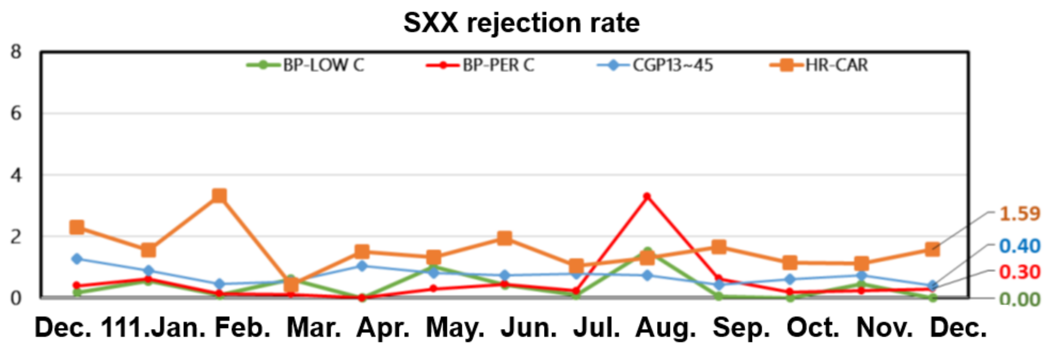

Fig.1. Sxx rejecting rate chart.

have been limited to full corner-chamfering for the most critical grades, while four-side scarfing is applied to the rest. However, considering the limited capacity for full chamfering operations, a project (T12) has been initiated to reduce the burden on the finishing section and to improve the quality of high-strength automotive steels produced by vertical bending casters.

2. RESEARCH METHOD

The study has been conducted in three major areas: high-temperature ductility measurement, optimization of secondary cooling and surface condition control, and mold tapering practices. The approaches are described as follows:

2.1 High-Temperature Ductility Measurement

Due to their unique alloy composition, crack-sensitive automotive steels differ significantly from conventional peritectic steels. Gleeble test specimens were prepared from production slabs and subjected to high-temperature tensile tests within the 600-1300°C range under conditions shown in Figure 2. During testing, tensile load and strain were recorded, and reduction of area (RA) and tensile strength (TS) were evaluated post-fracture. Mechanical performance at different temperatures was compared among grades to assess differences in the third brittle zones.

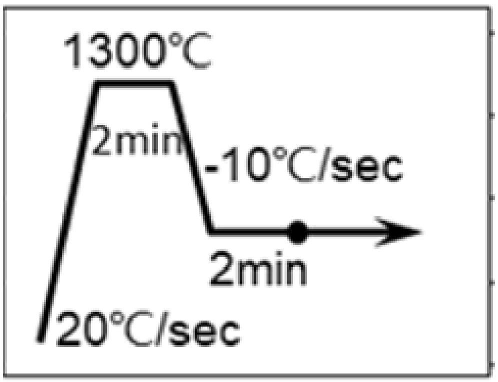

Fig.2. Gleeble heating curve.

2.2 Optimization of Secondary Cooling and Surface Condition Control (SCC)

Vertical bending casters are equipped with adjustable secondary cooling water zones along the vertical segment. Although parameter optimization has improved corner cracking in conventional steels, sensitive automotive grades still exhibit severe cracking. To address this, SCC technology was implemented, in which intensified water cooling in the early secondary cooling zone reduces slab surface temperatures below the austenite decomposition start temperature (Ar3). This suppresses the formation of polygonal ferrite (PF) during phase transformation and promotes uniform precipitation distribution, thus avoiding the formation of precipitate-free zones (PFZ) and enhancing slab ductility.

2.3 Chamfer Mold Practice

Chamfered molds had been previously used in a fixed-width mode. However, due to the diversity of customer order sizes, mold tapering has become a routine practice. Evaluation of production plans indicated that without mold tapering, slab production cycles could not exceed two days, highlighting the challenge of applying chamfered molds under variable-width operation. Analysis revealed that during the transition from narrow to wide molds, a prolonged gap formed between the copper mold and solidified shell, increasing the risk of breakout due to insufficient corner shell thickness.

To address this, the mold tapering control program was redesigned. After optimization, the application of chamfered molds was extended to sensitive high-strength automotive grades with added niobium or boron. The aim was to evaluate whether chamfered mold usage could reduce the incidence of corner cracks in these steels.

3. RESULTS AND DISCUSSION

3.1 High-Temperature Mechanical Behavior of High-Strength Steels

Three steel types were sampled: conventional peritectic steel, boron-added peritectic steel, and niobium-added peritectic steel. For conventional steel, ductility began to decline at approximately 950°C, reaching a minimum near 850°C before recovering at lower temperatures. This defined the third brittle zone. In contrast, the high-temperature mechanical properties of niobium and boron-added steels revealed an expanded brittle range. Both the upper and lower temperature limits were broadened, indicating increased susceptibility to cracking during casting. Additionally, niobium-added steels exhibited poor ductility recovery at lower temperatures—only reaching 30-40% of peak ductility, as shown in Figure 3—implying a higher risk of cracking in the latter stages of casting.

3.2 Mold Zone Intensive Cooling Analysis

Prior to the trials, slab solidification and cooling simulations were conducted to determine the influence of secondary cooling adjustments. Previous results confirmed that adjusting water flow in Zones *.1 and *.2 mainly affected temperatures in the bending segment, with minimal influence downstream. This suggested that intensified cooling under the mold would not destabilize end-of-strand temperatures. Simulations were used to

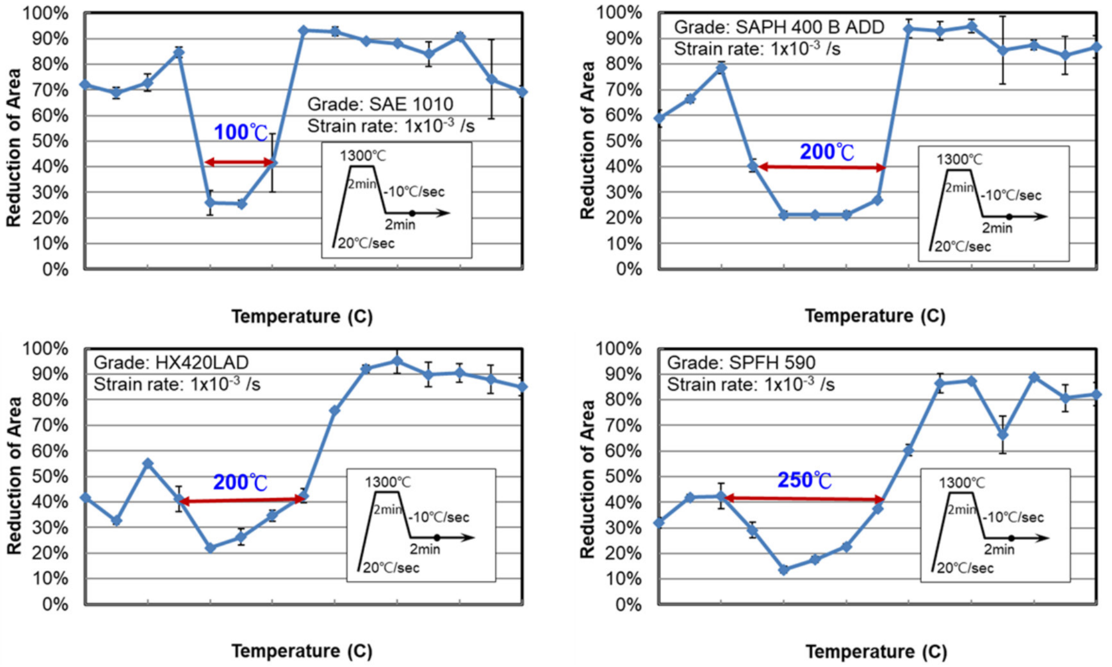

Fig.3. High-temperature mechanical behavior of different steel grades.

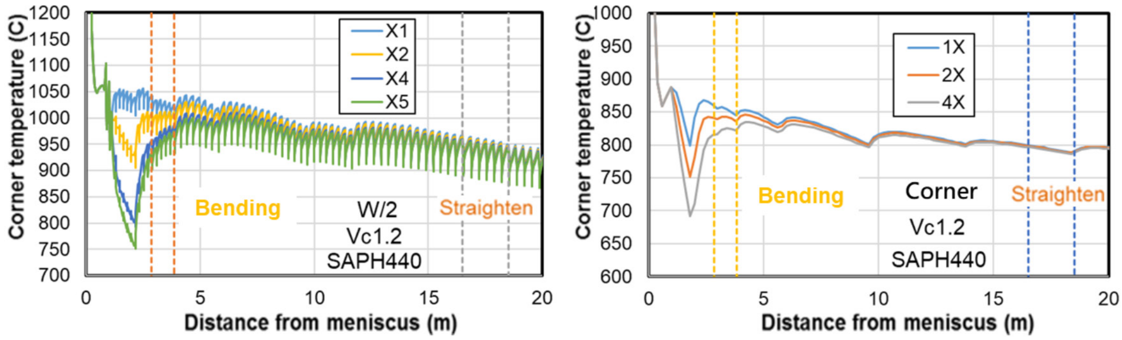

Fig.4. The effect of different water flow rates to the surface temperature of steel slabs.

estimate slab surface temperatures under different water flow multipliers in Zone 3x. To achieve target temperature reductions at the slab center, a fivefold increase in water flow was required, while corner temperatures could be reduced with only a twofold increase.

Practices were conducted with two intensified cooling settings—2X and 5X water flow. One strand was modified while the other served as the control. Rejection rates of hot-rolled coils were recorded and are presented in Figure 5. Results showed that 2X cooling performed better than 5X in suppressing corner cracks. However, neither condition significantly reduced the overall corner crack incidence compared to the control. Based on mechanical and thermal analysis, it was concluded that slab corners in the bending zone remained within the third brittle range (800-850°C). Under the current system limitations, intensive cooling was therefore ineffective in mitigating corner cracks in these steels.

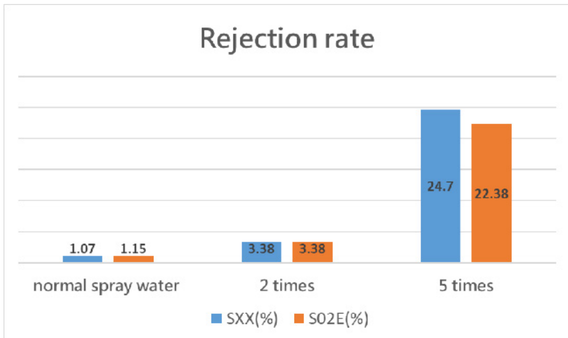

Fig.5. The result of the SCC test.

3.3 Chamfer Mold Practice

Chamfered mold production was validated using several steels, including conventional peritectic grades (SS400, SL250Y) and crack-sensitive grades (SPFH590M, SAPH440). Results from chamfered mold practices are shown in Figure 6. For both boron (Gr.40) and niobium (Gr.45) steels, the corner crack detection rates were significantly reduced compared to slabs cast with straight molds, by more than 4% in both cases.

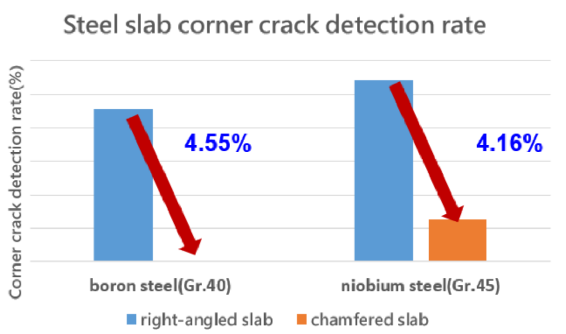

Fig.6. The corner crack detection rate of the chamfered slab and right-angled slab.

Figure 7 presents the S02E rejection rates in hot-rolled coils. Regardless of scarfing treatment, chamfered mold usage led to a substantial reduction in S02E defects. Though corner cracks were not fully eliminated, a 10.57% reduction in S02E rejection rate was observed in boron steels, demonstrating a strong improvement. Thermographic data indicated that slab corner temperatures in chamfered molds were approximately 60–80°C higher than those in straight molds. This elevated the slab corner temperature above 850°C during bending, allowing ductility to recover to ~50% of its original value and effectively reducing crack formation in sensitive steel grades.

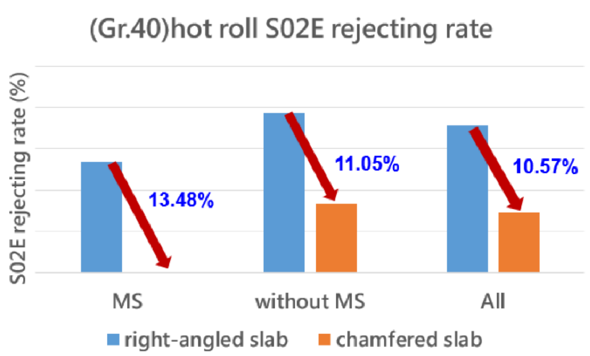

Fig.7. The S02E hot roll rejection rate of boron steel.

4. CONCLUSIONS

(1)The third brittle temperature range was approximately 100°C for conventional peritectic steels. This range expanded to 200°C in boron steels and 250°C in niobium steels. In the latter, low-temperature embrittlement extended to 600°C, indicating that corner cracks could form under both thermal and mechanical stress after strand exit.

(2)Sub-mold cooling practices with 2X and 5X water flow increases were completed. Although the 2X condition performed better, the overall corner crack detection rate remained higher than that of the control group. It was thus concluded that sub-mold cooling was ineffective under current equipment constraints.

(3)Chamfered mold configurations demonstrated that the use of chamfered molds for sensitive automotive grades (Gr.40 and Gr.45) significantly reduced corner crack incidence and S02E rejection rates. It is recommended that chamfered molds be adopted as the standard configuration for producing crack-sensitive automotive steels.

REFERENCES

1. 鈴木 洋夫, 西村 哲, 山口 重裕, “凝固組織を持つ種々の鋼の高温域における脆化特性,” 鉄と鋼, Vol. 65, No. 14, 1979, pp. 2038-2046, A1418.
2. Hirowo G. Suzuki, Satoshi Nishimura, and Shigehiro Yamaguchi, "Characteristics of Hot Ductility in Steels Subjected to the Melting and Solidification," Transactions of ISIJ, Vol. 22, No. 1, 1982, pp. 48-56, A721.
3. B. Mintz, S. Yue and J. J. Jonas, “Hot Ductility of Steels and Its Relationship to the Problem of Transverse Cracking During Continuous Casting,” International Materials Reviews, Vol. 36, No. 1, 1991, pp. 187-220, A1410.
4. B.G. Thomas, “High Temperature Mechanical Properties of Steel,” Brimacombe Continuous Casting Course, Vancouver, Canada, 2018.
5. C. M. Chimani, H. Resch, K. Mörwald and O. Kolednik, "Precipitation and Phase Transformation Modelling to Predict Surface Cracks and Slab Quality," Ironmaking and Steelmaking, Vol. 32, No. 1, 2005, pp. 75-79, A134.
6. Manfred M. Wolf, "Fine Intergranular Surface Cracks in Bloom Casting," Transactions of ISIJ, Vol. 24, No. 5, 1984, pp. 351-358, A720.
7. Chiaki Ouchi and Kazuaki Matsumoto, “Hot Ductility in Nb-bearing High-strength Low-alloy Steels,” Transactions ISIJ, Vol. 22, No. 3, 1982, pp. 181-189, A1532.
8. Xiaochuan Luo, Qiqi Xie, Yuan Wang, Cuie Yang,

"Estimation of Heat Transfer Coefficients in Continuous Casting under Large Disturbance by Gaussian Kernel Particle Swarm Optimization Method," International Journal of Heat and Mass Transfer, Vol. 111, 2017, pp. 1087-1097, A1523.
9. Kenji Taguchi et al., "Effect of Cooling Rate on Hot Ductility of Boron Containing Steel," CAMP-ISIJ, Vol. 28, 2015, p. 686, A1115.
10. B. Mintz and R. Abushosha, "Effectiveness of Hot Tensile Test in Simulating Straightening in Continuous Casting," Materials Science and Technology, Vol. 8, 1992, pp. 171-177, A1426.
11. B. Mintz and D. N. Crowther, "Hot Ductility of Steels and Its Relationship to the Problem of Transverse Cracking in Continuous Casting," International Materials Reviews, Vol. 55, No. 3, 2010, pp. 168-196, A1414.
12. Y. Maehara, Y. Ohmori, "The Precipitation of AlN and NbC and the Hot Ductility of Low Carbon Steels," Materials Science and Engineering, Vol. 62, No. 1, 1984, pp. 109-119, A1458.
13. Y. Maehara, K. Yasumoto, H. Tomono, T. Nagamichi, and Y. Ohmori, "Surface Cracking Mechanism of Continuously Cast Low Carbon Low Alloy Steel Slabs", Materials Science and Technology, Vol. 6, No. 9, 1990, pp. 793-806, A1423.
14. Yoshiki Ito, Toru Kato, Akihiro Yamanaka, Tadao Watanabe, "Improvement of Hot Ductility in Continuously Cast Strand by Ferrite Precipitation Control," Tetsu-to-Hagane, Vol. 89, No. 10, 2003, pp. 1023-1030, A1441.
15. Noriaki Baba, Kozo Ohta, Yoshiki Ito, and Toru Kato, "Prevention of Slab Surface Transverse Cracking at Kashima No.2 Caster with Surface Structure Control (SSC) Cooling," 2005 5th ECCC, Nice, France, 2005, pp. 128-135, A85.