Development of Hot-Rolled CSC HM550Y-FB Hole Expansion High-Strength Steel

YUNG-HSIANG CHUANG*, YU-JEN KUO*, TSUNG-HSIEN WANG*, MING-YEN TSAI and WEI LO****

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

The processability requirements of hot-rolled automobile steel are increasing day by day, given the increasingly complex morphology of automobile parts. It is not only a simple bending-forming process but also includes more demanding techniques such as flanging, edge stretching, and hole expansion. The formability was often evaluated using elongation or bending tests to predict the likelihood of processing failure. The critical technical indicator for flange forming and hole expansion is to improve the hole expansion capacity. It could be easier to meet the requirements for component manufacturing by enhancing the steel performance in hole expansion capability. Through optimized metallurgical composition design and controlled hot-rolling processes, including strengthening techniques such as grain refinement, precipitation, and a hard second phase, the strength of the steel has been enhanced. China Steel Corporation (CSC) has successfully developed hot-rolled hole-expansion high-strength steel with a minimum yield strength of 550 MPa, featuring a microstructure predominantly composed of ferrite and bainite. Hole-expansion steel is a key Advanced Precision Steel (APS) product promoted by CSC, offering excellent formability that can improve customer processing yields. CSC is committed to aligning with the automotive industry's safety performance and light-weighting demands by developing new products and continuously striving to provide high-quality steel to its customers.

Keywords: Ferrite-Bainite steel, Hole expansion, Advance High Strength Steels (AHSS), Advanced Premium Steel (APS)

1. INTRODUCTION

Today, the development and demand for automotive steel have increasingly shifted towards Advanced High-Strength Steel (AHSS). According to the World Auto Steel, AHSS is categorized into the following seven types: Dual Phase (DP), Ferrite-Bainite (FB), Complex-Phase (CP), Transformation-Induced Plasticity (TRIP), Twinning-Induced Plasticity (TWIP), Hot Formed Steel (HF), and Martensite Steel (MS). Ferrite-Bainite steel, characterized by its microstructure primarily consisting of ferrite and bainite, is known for its superior hole-expansion properties. This is because hard and brittle microstructures such as martensite and pearlite can lead to stress concentration, accelerating crack growth during hole expansion, which negatively affects hole expansion performance. The know-how for developing hole-expansion steel products among global steelmakers involves optimizing specific metallurgical compositions and employing appropriate hot-rolling processes to achieve varying ratios of ferrite and bainite microstructures, ensuring compliance with specified mechanical strength and hole expansion ratio requirements to meet stringent customer processing demands.

2. QUALITY CRITERIA

2.1 Demands of Hole-Expansion

The hole expansion steel is evaluated using international standards such as ISO 16630 and JIS Z 2256 to measure the hole expansion ratio. The test procedure is briefly described in Figure 1. The purpose of the hole expansion ratio test, as shown in Figure 2, is to reflect the increasing complexity of automotive component processing. The test samples closely resemble the processing methods and appearance of actual parts, highlighting the representativeness and importance of the hole expansion test in the context of automotive manufacturing.

The higher the hole expansion ratio (λ value), the steel can withstand greater hole expansion without cracking. Conversely, a lower λ value suggests that the steel will experience section rupture with only minor flanging, leading to increased processing defects and higher production or secondary repair costs. The hole expansion test simulates the complex multiaxial stresses

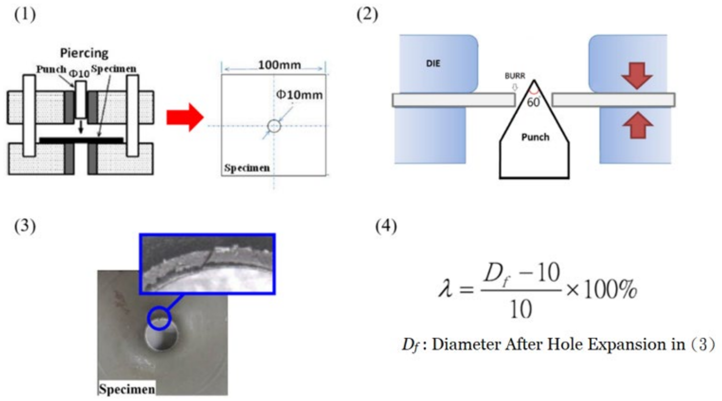

Fig.1. Preparation and Testing of Hole Expansion Test Samples (Ref: 1~4.)

Fig.2 Samples After Hole-Expansion Test and Typical Flanged Auto-Components (Ref: 5~6.)

experienced by the steel, and while there is a slight positive correlation between elongation in tensile tests and hole expansion properties, tensile tests alone cannot fully represent or replace hole expansion tests. This highlights the unique nature of hole expansion properties and the importance of developing hole expansion steel products.

2.2. Factors Affecting Hole Expansion

Both hole expansion testing and the flanging of components reveal that the origins of the crack are typically from micro-voids at the punch-out section. The formation and prevalence of these micro-cracks are primarily influenced by die design, material properties, and adjustments to the die clearances during punching and hole formation processes. Initial assessments can be made based on the quality of the punched cross-section; for example, excessive burrs or discontinuous cross-sections can lead to poorer hole expansion properties.

While techniques such as reversing burrs, adjusting dies, or grinding the cross-section can improve hole expansion properties and processing success rates, these methods can also increase production costs and reduce yield. Therefore, selecting appropriate hole expansion steel and comprehensively enhancing its hole expansion properties is crucial for processing issues and minimizing manufacturing problems and the resulting repair costs.

In addition to macro-level processing factors, grain size, and steel cleanliness also affect the hole expansion ratio. For example, inclusions, slag, and segregation in steelmaking can lead to the formation or concentration of micro-voids, which serve as nucleation for cracks. Among these, manganese sulfide (MnS) inclusions are particularly problematic. It is reported that when sulfur content increases from 0.001% to 0.003%, the hole expansion ratio drops significantly. This is because higher sulfur levels promote the formation of MnS inclusions, which are hard and brittle with poor ductility, adversely affecting hole expansion properties.

The grain size of the microstructure also impacts hole expansion characteristics. Literature shows that finer grains result in a higher hole expansion ratio. To enhance the hole expansion properties of steel, a finer grain structure is preferable. In the development of hole expansion steel products, CSC improves steel cleanliness through refining facilities and deep desulfurization processes. Additionally, CSC employs specialized patented processing techniques during hot rolling to achieve a uniform and finer microstructure, significantly increasing the hole expansion ratio.

3. DEVELOPMENT OF HOLE EXPANSION STEEL

3.1 Chemical Composition

To meet the requirements of high strength, and excellent hole-expansion ratio, the product's composition is carefully designed. This involves reducing the carbon content to decrease carbide such as pearlite etc. Micro-alloys including niobium (Nb), vanadium (V), and titanium (Ti) are added to improve both strength and finer grain size. Moreover, extra low levels of phosphorus (P) and sulfur (S) ensure the avoidance of detrimental inclusions.

3.2 Rolling Process

The slabs were soaked at 1100℃-1300℃, and then hot rolled. The finishing rolling temperature is around 800-950℃. After finishing rolling, hot rolled sheets were cooled by a special laminar cooling process. The coiling temperature was designed to obtain more amount finer ferrite, little bainite, and less pearlite without martensite

4. RESULTS AND DISCUSSION

The new product development has been completed through the aforementioned composition design and production processes. The new product in this study is designated as CSC HM550Y-FB corresponds to similar strength specifications as listed in Table 1, such as BS EN 10149-2 S550MC or ASTM A1011 GR.80. The requirements of S550MC and GR.80 products contain only tensile properties, including yield strength, tensile strength and elongation. CSC HM550Y-FB could provide not only good tensile properties but also a good hole expansion ratio, as shown in Table 1. This makes it suitable for applications such as automotive chassis components or airbag inflators is has been promoted and has received positive feedback and quality trust from customers.

5. CONCLUSIONS

CSC has achieved successful development of the CSC HM550Y-FB CSC's own steel grade through a series of strategic implementations. Firstly, the composition design was optimized by reducing the carbon content and carefully controlling the levels of phosphorus and sulfur to obtain a higher cleanliness and less carbide of the steel.

Secondly, significant improvements were made by adding Nb, Ti, and V micro alloys, which resulted in grain refinement and precipitation strengthening. This grain refinement technique led to a notable enhancement in hole expansion property, contributing to the overall flanging and machining performance of the steel.

Moreover, by improving the hole-expansion property, the steel has met customer processing requirements and reduced the costs associated with secondary processing or repairs, as confirmed by customer feedback. The new product continues to expand its application and has become an APS in CSC's hot-rolled product. China Steel Corporation is also actively developing a series of strength grades for hot-rolled hole-expansion high-strength automotive steels, offering customers high-quality steel and new product options. This ongoing development aims to advance in collaboration with customers and the industry.

REFERENCES

1. Kyohei KAMIBAYASHI, Yutaka TANABE, Yoshito TAKEMOTO, et al., Influence of Ti and Nb on the Strength-Ductility-Hole Expansion Ratio Balance of hot-rolled Low-carbon High-strength Steel Sheets, ISIJ International, Vol.52, No.1, pp.151-157, 2012.
2. Surajit Kumar Paul, Moniddepa Mukherjee, Saurabh Kundu, Sanjay Chandra, Prediction of hole Expansion Ratio for Automotive Grade Steels, Computational Materials Science, Vol.89, pp.189-197, 2014.
3. WorldAutoSteel website, from https://ahssinsights.org/forming/testing-characterization-forming/hole-expansion-testing/
4. Xinping Chen, Haoming Jiang, Zhenxiang Cui,

Table 1 Mechanical Properties for CSC HM550Y-FB* and similar spec.

Spec. Requirement	YS (MPa)	TS (MPa)	EL (%)	λ－HE(%)
ASTM A1011 GR.80	550 min	620 min	16 min	-
EN 10149-2 S550MC	550 min	600~760	12 min	-
CSC HM550Y-FB	550 min	620 min	16 min	50 min
CSC HM550Y-FB Typical results	586	652	19.4	62.5

* H: Hot Rolled; M: Machining; FB: Ferrite and Bainite

Changwei Lian, Chao Lu, Hole Expansion Characteristics of Ultra High Strength Steels, 11th International Conference on Technology of Plasticity, ICTP 2014, pp.19-24, 2014.

5. Zwickroell website, from https://www.zwickroell.com/industries/materials-testing/sheet-metal-forming/hole-expansion-test/determination-of-edge-crack-sensitivity-iso-16630/
6. Dreamstime website from https://cn.dreamstime.com