Clean Steels for More Reliable and Cost-Effective Steel Products

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The continuous demand from customers for more reliable and cost-effective steel products presents both opportunities and challenges for the steel industry. Reliability is a crucial factor in various applications that rely on steel, and meeting these demands requires a comprehensive approach that involves understanding the intrinsic relationships between product design, steel processing and mechanical properties.

By adopting this fundamental metallurgical approach and implementing a tailor-made Best Practice, Ternium steel plants can consistently produce cleaner steels across different product lines and plant configurations. This tailor-made Best Practice was based on the following issues:

• New classification criteria about what is called “Clean Steel” in Ternium.
• Recommended thresholds for the main primary metallurgy, secondary metallurgy and continuous casting key process parameters deviations.
• Downgrading of steel grades according to more stringent quality requirements.

This leads to improved product reliability, reduced customers claims, and enhanced customer satisfaction, with a novel approach based on fundamental practices adaptable to different steel plants configuration and products.

Keywords: Clean steels; best practice; non-metallic inclusions, robust design, product reliability, structural steels.

INTRODUCTION

The continuous demand by the automotive, heavy transportation and energy industries for stronger, tougher, lighter and more cost-effective steel products represents a series of unique opportunities and challenges for the steel industry. Reliability is very relevant for such applications and require developing fundamental understanding of the intrinsic relationships between alloy design - steelmaking and thermomechanical processing design - final microstructure and mechanical properties.

This work presents an example of the development of standardized industrial best practices conceived to prevent risky quality conditions affecting structural product performance, through the design of steels with high inclusionary cleanliness and consistency, for various final applications.

The main goal of the project was to improve the cleanliness of steel during the refining process and achieve a standardized product quality that meets cleanliness targets.

BACKGROUND

Non-metallic inclusions (NMIs) are made up of a material different to the primary composing material of the steel matrix and can be classified by:

• Its chemical composition (oxides, sulphides, etc.), “endogenous” (originated from the steel making process), “external” (refractory material fragments, slag, etc.).
• Their critical size as macro-inclusions (big enough to cause immediate failure while processing or using the steel), or micro-inclusions (all the rest).
The effect of NMIs cannot be completely eliminated after hot rolling, there still will be a difference in the stiffness between the steel matrix and the NMIS (a weak point or stresses concentrator in the material).

NMIs in steels can significantly influence their functional properties, impacting various mechanical and metallurgical characteristics (Figure 1).

Here are some ways in which NMIs can affect the functional properties of steels:

Low Temperature Toughness: Controlling the type, size, and distribution of inclusions is essential to improving low-temperature toughness and preventing catastrophic failures.

Ductile Fracture Resistance: NMIs can influence the ductile-to-brittle transition temperature, affecting the propensity of a steel to undergo ductile or brittle fracture. Reducing detrimental inclusions can enhance ductile fracture resistance.

Fatigue Resistance: NMIs can act as stress raisers, promoting fatigue crack initiation and propagation (Figure 2). High-stress concentration around inclusions can lead to premature fatigue failure. By minimizing harmful inclusions, the fatigue resistance of steels can be improved, allowing them to withstand repeated loading without failure.

Weldability: Inclusions can affect the weldability of steels by influencing the formation of weld defects, such as porosity and cracks. Certain types of inclusions can lead to reduced weld strength and integrity. Optimizing steel cleanliness and controlling inclusions are vital for ensuring good weldability and weld quality.
TECHNICAL APPROACH

Through a fundamental metallurgical approach, a Best Practice was established for the production of Clean Steel in Ternium’s plants, applicable to different products and steel plants configurations (Figures 3 and 4).

This standardized common Best Practice was based on the following issues:

- New classification criteria about what is called “Clean Steel” in Ternium.
- Steel best practice definition (Recommended thresholds for key process parameters deviations).
- Downgrading of steel grades according to more stringent quality requirements.

![Diagram of metallurgical refining and casting facilities overview of TERNIUM steelmaking plants.](image)

<table>
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<th>Nominal Capacity (Million tonnes per year)</th>
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<th>DIK</th>
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Figure 3: Metallurgical refining and casting facilities overview of TERNIUM steelmaking plants.

![Images of BOF converter, Continuous casting, Twin RH degasser, and Tank VOD degasser.](images)

Figure 4: Metallurgical refining and casting facilities overview of TERNIUM steelmaking plants.

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New classification criteria about what is called “Clean Steel” in Ternium
Ternium's Quality Policy commits high quality standards to its products. Based on this concept, three LEVELS of Clean Steels were defined:

- Clean steel LEVEL 1 – Ultra clean steel
- Clean steel LEVEL 2 – Special steels
- Clean steel LEVEL 3 – Standard steel

For each level of clean steel, inclusion cleanliness targets were defined based on the product application (Figure 5). Limits for the severity of micro-inclusion content and oversize inclusions were established for each level of clean steel, with reference to ASTM E45 standard.

Figure 5: Steel cleanliness requirement according to product application.

Steel Best Practice definition
Recommended thresholds were defined with present installation and operative conditions taking into account the main primary metallurgy, secondary metallurgy and continuous casting key process parameters deviations.

Identification of Key Process Parameters: The project started by identifying the main key process parameters that affect the cleanliness of steel during the refining process. These parameters were determined through controlled heat treatments and steel sampling at different stages of refining and casting (Figure 6). This allowed the team to identify key process parameters and thresholds that have an impact on steel cleanliness and to do preventive retention of heats with potential downgrade (Figure 7) for further analysis and/or inspection, previous to delivery. In addition, any kind of non-desirables transitory effects should be prevented. For example, slag transfer from BOF (or EAF) to ladle/ ladle to tundish / tundish to mould, subsurface entrapments, ladle reoxidation due to non-free openings, low levels of tundish, etc.
Figure 6: Sampling and analysis over the process, starting after the tapping.

Figure 7: Identified key process parameters for the Best Practice (CLEAN Steels).
**Assessment of Inclusion Evolution:** The evolution of inclusions was studied for both calcium treated and non-calcium treated steel grades. This step helped understand how different refining practices and treatments influenced the type and quantity of inclusions in the steel. In Figure 8, the manufacturing strategy for the production of clean steels in one of the steel plants is shown as an example.

![Diagram showing clean steel production process](image)

**RESULTS**

**Evaluation of Steel Cleanliness in Hot Rolled Products:** The steel cleanliness was evaluated in hot rolled products accordingly to ASTM E45 standard (method « A » worst-field rating). In this rating the specimen is judged for each type of inclusion by assigning the highest severity rating observed for each inclusion type. Ternium has set internal limits for NMIs more stringent or demanding than those specified by customers. This can be seen as a preventive approach to supply steels that exceeds the minimum requirements expected by customers. Figures 9 and 10 show evolution of the percentage of hot rolled samples with NMIs above these internal limits, for the corresponding applicable Clean Steel levels. Non-compliant hot rolled coils and wire rods are retained for further analysis and/or inspection, previous to delivery.
Improvement in Customer Complaints: The performance of the products at the clients’ end was monitored to validate the effectiveness of the implemented best practices. This step likely included gathering feedback from clients and ensuring the products met their requirements and standards. For example, UT detections in welded tubes for oil & gas applications and fatigue resistance in wire rod coil springs.

There was a 66% reduction in customer complaints for Ultra Clean Steels and a 100% decrease for Special Steels. This suggests that the improved steel cleanliness led to greater customer satisfaction and fewer product-related issue (Figure 11).
Standardized Product Quality: By optimizing the refining processes and controlling key parameters, the project aimed to achieve standardized product quality. This means that regardless of the steel plant's configuration, the final product met consistent quality standards.

Reduced NMIs Severity: The primary focus of the project was to reduce the severity of non-metallic inclusions in the steel. By identifying and optimizing the key process parameters, the project successfully achieved this goal.

Improvement in Customer Complaints: The project also resulted in higher customer satisfaction, as evidenced by a reduction of 66% in customer complaints for Ultra Clean Steels and a complete elimination (100% reduction) of customer complaints for Special Steels. This indicates that the steel products met or exceeded the customers' requirements and expectations.

CONCLUSIONS

The primary outcome of the project was the delivery of improved product quality to the market, through a metallurgical path that meets high cleanliness standards in a wide range of products and processes.

Overall, this project's success demonstrates the importance of identifying and controlling key process parameters to improve steel cleanliness and product quality. The reduction in non-metallic inclusions and customer complaints indicates enhanced product reliability and market competitiveness.

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