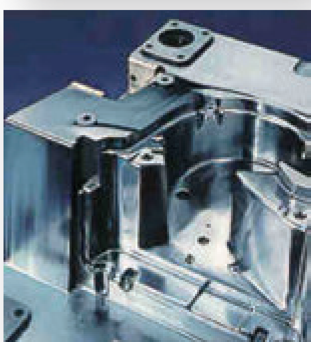
FINELINE™ STEELS

HIGH QUALITY STEELS WITH VERY LOW SULFUR LEVELS

PLATE STEELS

- **Pressure Vessels**
- **Military Alloy Plate Steels**
- **Mold Steels**
- **Bridges**
- **Truck Liners**



The demand for **PLATE STEELS** with a variety of improved properties stimulated the development of the FINELINE™ process that can be applied to most steels, resulting in low-sulfur, vacuum-degassed plate steel products with calcium treatment.

Introduced in 1977 with a maximum sulfur level of .010%, FINELINE steels successfully addressed the market concern about lamellar tearing of conventional plate steels when used in highly restrained welded joints.

For certain applications, where even more stringent mechanical properties and internal cleanliness were required, the next generation of FINELINE steels was developed in 1985 with a maximum sulfur level of .005%. Military alloy plate steels took advantage of FINELINE steel's more uniform tri-axial mechanical properties, while the tooling industry benefited from the improved cleanliness.

Introduction

In 1990, to satisfy the requirements for HIC (hydrogen-induced cracking) testing of plate steels used in the process vessels, A516 steel with a maximum heat analysis of .002% sulfur was offered. For this grade and application, the maximum sulfur level for FINELINE steel was further reduced to .001% in 1992.

Although sulfur levels of .001% and .002% have been marketed primarily in A516 plates, Cleveland-Cliffs Plate mills also produce other specifications to very low sulfur levels.

The FINELINE process can be applied to any plate steel melted in Coatesville's electric furnace steelmaking complex where heats of 165 tons are produced. The equipment at this facility makes possible the rapid and efficient production of steels to precisely controlled chemistries essential to the FINELINE process.

FINELINE plate steels are available from Cleveland-Cliffs as flat plate or cut to desired shape as a flamecut product.

HISTORY

1957 - 1975	The first electric arc furnace is installed at Cleveland-Cliffs, Coatesville, Pennsylvania steelmaking facility and becomes the first plate mill to use electric furnace melting. The Coatesville melt shop becomes an all-electric steel producer with four electric arc furnaces by 1975 when it closes its last open-hearth melting furnace.
1971	An Electro-Slag Remelting (ESR) facility for the production of ultra-clean thick plate steels is installed. It addresses the cleanliness requirements of the nuclear and mold and die industries.
1975	Coatesville becomes the first U.S. steel company to receive national nuclear certification from the American Society of Mechanical Engineers (ASME)
1977	A Calcium Argon Blowing (CAB) facility for sulfur reduction and inclusion shape control is installed. The company introduces FINELINE steel with 0.01% maximum sulfur.
1985	FINELINE steel with 0.005% maximum sulfur is introduced.
1988	A ladle refining facility, consisting of a ladle furnace and degasser, is installed at the Coatesville melt shop. One 165-ton electric furnace is used to melt scrap and subsequent refining is performed in the ladle refining facility, improving production and quality levels from the previous four-furnace operation.
1990	FINELINE steel with 0.002% maximum sulfur is introduced.
1992	FINELINE steel with 0.001% maximum sulfur is introduced.
1994	Argon bubbling strips in continuous caster tundish and argon shrouding of ingots started.

FINELINE™ Process

The equipment at Cleveland-Cliffs' Coatesville, Pennsylvania steelmaking facility, depicted schematically in Figure 1, makes the production of FINELINE steel possible.

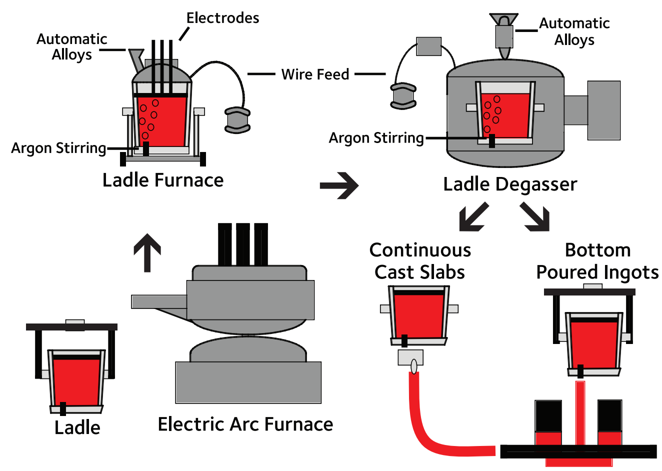
Scrap metal is melted and some ferroalloys are added to the molten steel in the electric arc furnace. Once the steel is melted, it is poured into a specially designed ladle and moved to the ladle furnace station. It is here that the FINELINE process begins.

Like the electric arc furnace, the ladle furnace has three graphite electrodes that when lowered close to the steel's surface, create an electric arc with extremely high temperatures. The intense heat is used to melt alloy additions, fuse slag-making materials and maintain or increase the molten steel's temperature as required for refining. The proper "ingredients" to make the particular grade of steel are added and calcium treatment, using calcium wire feeding, is performed.

The entire ladle of refined, calcium-treated molten steel is then placed inside a sealed vacuum chamber, the ladle degasser, where the steel is stirred by blowing inert argon gas through the bottom of the ladle. The violent churning of the steel releases undesirable gases, which are removed by the vacuum. Since the molten steel is isolated from outside environmental influences, this method of gas removal produces a "cleaner" steel product than do systems where the ladle is exposed to the atmosphere. Final alloy chemistry adjustment, as well as further calcium treatment to complete the FINELINE process, can also be made at the degassing station.

The steel is then continuous cast or bottom poured into ingot molds where solidification into semi-finished form occurs for subsequent rolling to final plate size.

FIGURE 1



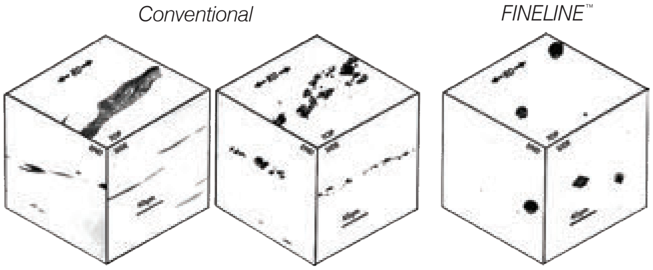
Internal Quality

The reduced sulfur level in FINELINE steels not only results in fewer inclusions for improved micro-cleanliness, but also, due to calcium treatment, the remaining inclusions resist elongation during the plate rolling operation and tend to remain spherical. This is shown in the photomicrographs in Figure 2, taken at the approximate mid-gauge of the plates. This "shape control" contributes to the improved ultrasonic quality, macro cleanliness and mechanical properties of FINELINE steels.

FIGURE 2

Inclusions in Structural Plate Steels

Conventional *FINELINE™*



Manganese Sulfides *Aluminum Oxides* *Calcium Modified*

ULTRASONIC TESTING

Ultrasonic examination permits 100% volumetric inspection of steel plate. FINELINE plates up to 6 in. thick, and thicker plates, depending on total pattern weight, can be ordered to meet restrictive ASTM A578 Level III acceptance criteria. If more restrictive requirements are desired, please inquire with Cleveland-Cliffs Plate professionals.

MICRO CLEANLINESS

Metallographic evaluation can be used to quantify the cleanliness of FINELINE steels. Please consult a representative at Cleveland-Cliffs Plate mills about your specific acceptance level criteria, if applicable.

Mechanical Parts

STRENGTH AND DUCTILITY

The cleanliness and inclusion "shape control" of FINELINE steels lead to greater uniformity and improved strength and ductility. In conventional plate steels, transverse and through-thickness mechanical test values are normally much lower than those from longitudinal specimens.

FINELINE plates, however, produce not only higher and more uniform mechanical property values, but values that more closely approximate longitudinal results, regardless of the test specimen orientation.

Table 1 demonstrates, as a percentage of the longitudinal specification values, the Z-direction strength of FINELINE steel with various maximum sulfur levels.

A measurement of steel ductility, percent reduction of area (% RA), improves with declining sulfur levels and shape control, as shown in Table 1. Figure 3 further demonstrates these phenomena.

TABLE 1
FINELINE™ Steel's Z-Direction Properties*

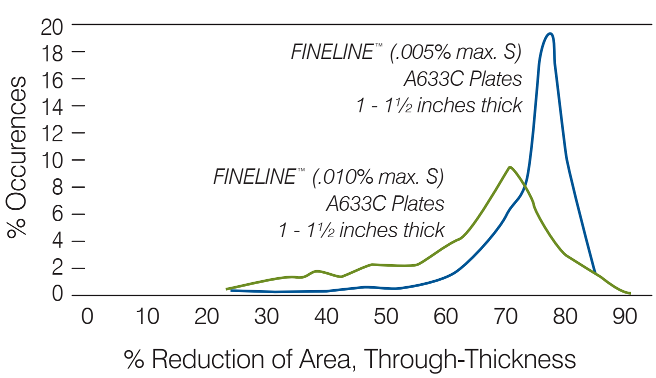
% Sulfur	Reduction in Area	Z-Direction Strength (% of Longitudinal Specification)
.010 max.	25% min.	75% min.
.005 max.	40% min.	90% min.
.002 max. **	50% min.	95% min.

* *Applies to normalized or quenched and tempered steels. Refer others to Cleveland-Cliffs Plate mills.*

* *ASTM A770 applies to plates up to 10 in. thick (test location is at center-thickness). For plates greater than 10 in. thick, Cleveland-Cliffs tests at the quarter thickness location.*

** *Currently available in A516 Grade 70. Other specifications will be considered on request. Also available as 0.001% maximum.*

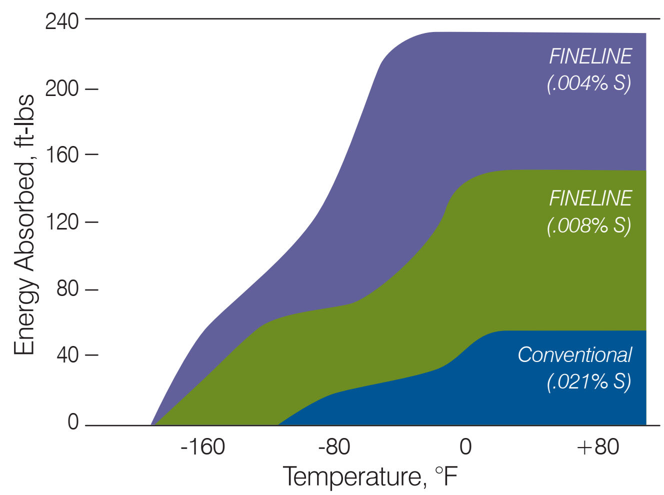
FIGURE 3
Distribution of Through-Thickness Reduction of Area



TOUGHNESS

The reduced sulfur levels of FINELINE steels also increase the steels' notch toughness. FINELINE plates subjected to Charpy V-notch impact testing showed an increase in longitudinal, transverse and through-thickness toughness value when compared to conventionally melted plate steels. Energy absorption ranges, based on Cleveland-Cliffs' testing, are displayed in Figure 4.

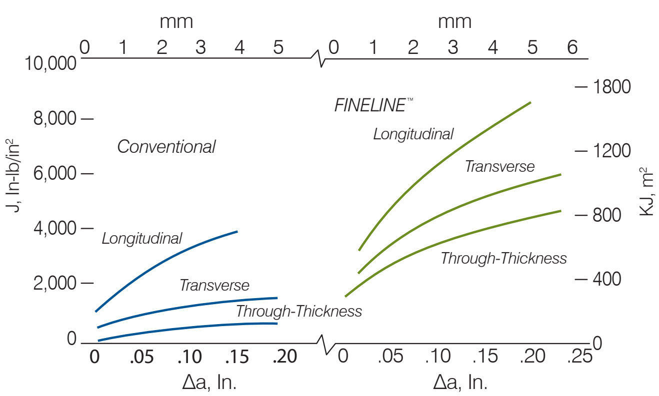
FIGURE 4
Comparison of Charpy V-Notch Energy Absorption for Normalized 1" – 2" Thick
ASTM A633C Plates, Transverse Orientation



The U.S. Army "Stryker" armed personnel carrier uses armor plate produced with FINELINE™ processing for improved toughness and spalling resistance.

FIGURE 5

J-Integral Fracture Toughness of A588A at +75°F One-Inch Thick Specimens with 25% Side-Grooves, Slow Loading Rate



APPLICATIONS

Improvements made in the cleanliness and mechanical properties of FINELINE steels over the years have been used to advantage in a number of industries for many applications, ranging from structural to process vessel.

Table 2 shows by market and application, the desired properties offered by FINELINE processing. A number of these applications are shown pictorially and explained throughout this brochure.

TABLE 2

Typical Applications for Cleveland-Cliffs FINELINE™ Steels

Market	Use	Properties Required by Designers
Hydrocarbon Processing, Storage and Production	Process vessels LNG tanks Offshore platforms	Toughness, HIC Resistance Toughness Lamellar tearing resistance and toughness
Military	Armor	Toughness and resistance to spalling
Construction and Mining Equipment	Cranes and excavator components Abrasion resistant applications	Low temperature toughness and lamellar tearing resistance Formability and toughness
General Purpose	Plastic injection molds Rotary kilns	Microcleanliness for quality of polishing Lamellar tearing resistance
Power Generation	Hydroelectric turbines	Lamellar tearing resistance
Construction	Bridges	Toughness

HYDROGEN-INDUCED CRACKING (HIC)

The refining and processing of "sour" petroleum can cause damage to process vessels and has created one of the most recent and larger consuming markets for FINELINE steel.

Atomic hydrogen, driven off during processing, can nucleate as hydrogen gas and cause blisters to form at inclusions within the vessel's steel shell. These "gas pockets" can become starting points for cracking which, if it continues, can cause catastrophic failure of the pressure-retaining steel wall. Concern over this phenomena, known as hydrogen-induced cracking, or HIC, has led to the development of test standards by the National Association of Corrosion Engineers (NACE) to be applied to steels destined for hydrogen service.

To meet these HIC-testing standards, FINELINE processed A516 steels with a heat analysis of .002% or .001% maximum sulfur, the sulfur level being dependent on the specified test result criteria, was introduced. The lower sulfur levels and smaller, shape-controlled sulfide inclusions that remain, minimize the potential for hydrogen blistering and HIC.

More detailed information on HIC-testing is available on request.

All U.S. Navy alloy steels are produced by Cleveland-Cliffs with FINELINE™ processing for improved toughness.

Technical Literature

The following papers on low-sulfur, calcium-treated steels have been prepared for technical presentations and publications. They are available upon request.

1. *The Interaction of Advanced Steelmaking Techniques on Inclusions, Toughness and Ductility in A533 Grade B Steels," A. D. Wilson, ASM Materials Application Conference, 1976.*
2. *"Mechanical Property Improvements Using Calcium Inclusion Shape Control," W. W. Scott, Jr., ASME Joint Conference of Petroleum and Pressure Vessel and Piping Division, Mexico City, 1976.*
3. *"Fatigue Crack Propagation in A533 Grade B Steels," A. D. Wilson, Transactions ASME, Journal of Pressure Vessels and Piping, August 1977.*
4. *"The Improvements in the Mechanical Properties of Heavy Gauge A516-70 Carbon Steel," R. H. Elwell, J. K. Stratton, R. A. Swift, Effects of Melting and Processing Variables on the Mechanical Properties of Steel, ASME, 1977.*
5. *"Through-Thickness Testing of Rolled Plate," D. A. Boe and R. A. Swift, 17th Annual Conference of Metallurgists, Montreal, August 1978.*
6. *"Calcium Treatment of Plate Steels and its Effects on Fatigue and Toughness Properties," A. D. Wilson, Offshore Technology Conference Proceedings, 1979.*
7. *"The Influence of Inclusions in the Fatigue and Toughness Properties of A516 Grade 70 Steels," A. D. Wilson, Transactions ASME, Journal of Engineering Materials and Technology, July 1979.*
8. *"Characterization on Plate Quality Steel Using Various Toughness Measurement Techniques," A. D. Wilson, Elastic Plastic Fracture, ASTM STP 668, 1979.*
9. *"The Effect of Inclusions on the Fracture Properties of A387-22 Steel Plate,"*
A. D. Wilson, Advanced Materials for Pressure Vessel Service with Hydrogen at High Temperatures and Pressures, MP–18, 1982.
10. *"Friction Weld Ductility and Toughness as Influenced by Inclusion Morphology, "*
A. D. Wilson, et al, Welding Journal, July 1983.
11. *"Influence of Inclusions on the Fracture Properties of A588A Steel," A. D. Wilson, ASTM STP 833, Philadelphia 1984.*
12. *"Characterizing Inclusion Shape Control in Low Sulfur C-Mn-Cb Plate Steel," A. D. Wilson, presented International Conference of Technology and Applications of HSLA Steels, Philadelphia, October 3, 1983.*
13. *"Fatigue Crack Propagation in Steels – The Role of Inclusions," A. D. Wilson, The Metallurgical Society of AIME Book, Fracture: Interactions of Microstructure, Mechanisms and Mechanics, 1985.*
14. *"Hydrogen-induced Cracking (HIC) Resistance of A516 Grade 70 Plate Steel," E. G. Hamburg, A. D. Wilson, AIME-TMS Conference, October 1989.*
15. *"Ongoing Challenges for Clean Steel Technology," A. D. Wilson, Clean Steel Technology, ASM International, 1992.*
16. *"Properties and Behavior of Modern A387 Cr-Mo Steels," A. D. Wilson, C. R. Roper, K. E. Orie, F. B. Fletcher, PVP-Vol. 239, Serviceability of Petroleum, Process and Power Equipment, 1992, ASME.*
17. *"HIC Testing of A516 Grade 70 Steels," A. D. Wilson and E. G. Hamburg, NACE Corrosion 93, 1993.*
18. *"Clean Steel Technology – Fundamental to the Development of High Performance Steels", A. D. Wilson, ASTM STP 1361, 1999.*
19. *"Properties of Recent Production of A709 HPS 70W Bridge Steels", A. D. Wilson, International Symposium on Steel for Fabricated Structures, ASM International, 1999.*
20. *"Development of an Improved HPS 100W Steel for Bridge Applications", A. D. Wilson, J. H. Gross, R. D. Stout, A. L. Asfahani, S. J. Manganello, International Conference on Microalloyed Steels, ASM International, 2002.*

Concern for hydrogen-induced cracking (HIC) susceptibility of plate steels used to fabricate vessels for processing petroleum and petrochemicals significantly increased the demand for the low-sulfur levels with shape control offered by FINELINE™ steels.

FINELINE™ STEELS

Additional Technical Information

MATERIAL TEST CERTIFICATE

A material Test Certificate, identifying the source of the steel plates as Cleveland-Cliffs Plate LLC, will be included for delivery with each shipment.

Cleveland-Cliffs' HARDWEAR® steels are used in truck liners. FINELINE™ processing gives them improved toughness and formability.

Steel bridges in the U.S.A. are increasingly using new high-performance steels (HPS 50W, HPS 70W, HPS 100W) produced by Cleveland-Cliffs with FINELINE™ practices for improved toughness.

About Cleveland-Cliffs Inc.

Cleveland-Cliffs is the largest flat-rolled steel producer in North America. Founded in 1847 as a mine operator, Cliffs also is the largest manufacturer of iron ore pellets in North America. The Company is vertically integrated from mined raw materials, direct reduced iron, and ferrous scrap to primary steelmaking and downstream finishing, stamping, tooling, and tubing. The Company serves a diverse range of markets due to its comprehensive offering of flat-rolled steel products and is the largest supplier of steel to the automotive industry in North America. The Company is headquartered in Cleveland, Ohio with mining, steel and downstream manufacturing operations located across the United States and in Canada. For more information, visit www.clevelandcliffs.com.

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