THE CURRENT TECHNOLOGICAL FRONTIERS OF THE DEVELOPMENT OF SOUR SERVICE HEAVY PLATES

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October 2018

INTRODUCTION

Pipes for long distance transmission of liquid or gaseous hydrocarbons are a **very important application for steel**.

Only in **Alaska** there is about **6,400 km of pipelines**, with diameter ranging from 1.0 to 1.5 m – this represents a very huge quantity of specialty steels.

Generally such ducts operate under a pressure that corresponds to **72% of the pipe yield strength** specified value, but in the future this value can increase to **80%**.

INTRODUCTION

Technical requisites to be satisfied under simultaneous minimum costs:

- ✓ **Increasing levels of mechanical strength** to allow greater values of pressure and, consequentely, higher transport capacity;
- ✓ **High toughness**, to increase operational safety of the duct;
- ✓ **Weldability**, to reduce costs and also to improve operational safety.

These demands are being satisfied through the use of **microalloyed steels submitted to TMCP**.

The ever increasing operational demands to be satisfied by pipelines are pushing the present **metallurgical technology frontiers**.

INTRODUCTION

There are three **metallurgical challenges** to be overcome:

- ✓ The occurrence of **inverse fracture in the DWTT specimens**, which prevents the evaluation of the fracture surface;
- ✓ The presence of **hard spots** in the pipes, which affect their HIC resistance;
- ✓ New microalloyed steel designs using **low Mn and high Nb**.

The activities that are being developed at **Gerdau Ouro Branco** on these topics will now be presented, within its objective of establishing itself as a new reliable and high performance steel supplier for this application.

INVERSE FRACTURE IN DWTT SPECIMENS

DWTT was developed in the early 1960's because the results of **absorbed energy and ductile area fraction** provided by the Charpy test were not sufficient to prevent long propagation of brittle fractures in pipelines when the thickness of the tube was greater than that of the specimen used.

The specimen of DWTT includes the **full thickness of the plate**, in order to get a reliable correlation between the ductile-brittle transition temperatures obtained in the laboratory and the one actually associated with the tube in its actual application.

A **fundamental condition** for this is the initiation of the crack with a brittle mode and its subsequent propagation with a ductile mode. The ductile area fraction at the fracture surface indicates the **ability of the material to intercept the brittle crack**.

INVERSE FRACTURE IN DWTT SPECIMENS

Battelle Institute: steel used in large diameter pipes will have sufficient toughness and will not exhibit brittle fracture under real conditions provided that the **ductile area fraction at the fracture of the specimens after DWTT is of at least 85%**.

After almost 60 years, pipe steels toughness knowledge are facing challenges:

- ✓ The **fundamental knowledge** about the concept of DWTT and the definition of the toughness standards are almost forgotten, as many specialists have retired;
- ✓ New pipe steels are presenting **unprecedented levels of mechanical strength and toughness**, which are creating new problems for the analysis of the results obtained in the DWTT. One of them is the so called **inverse fracture**.

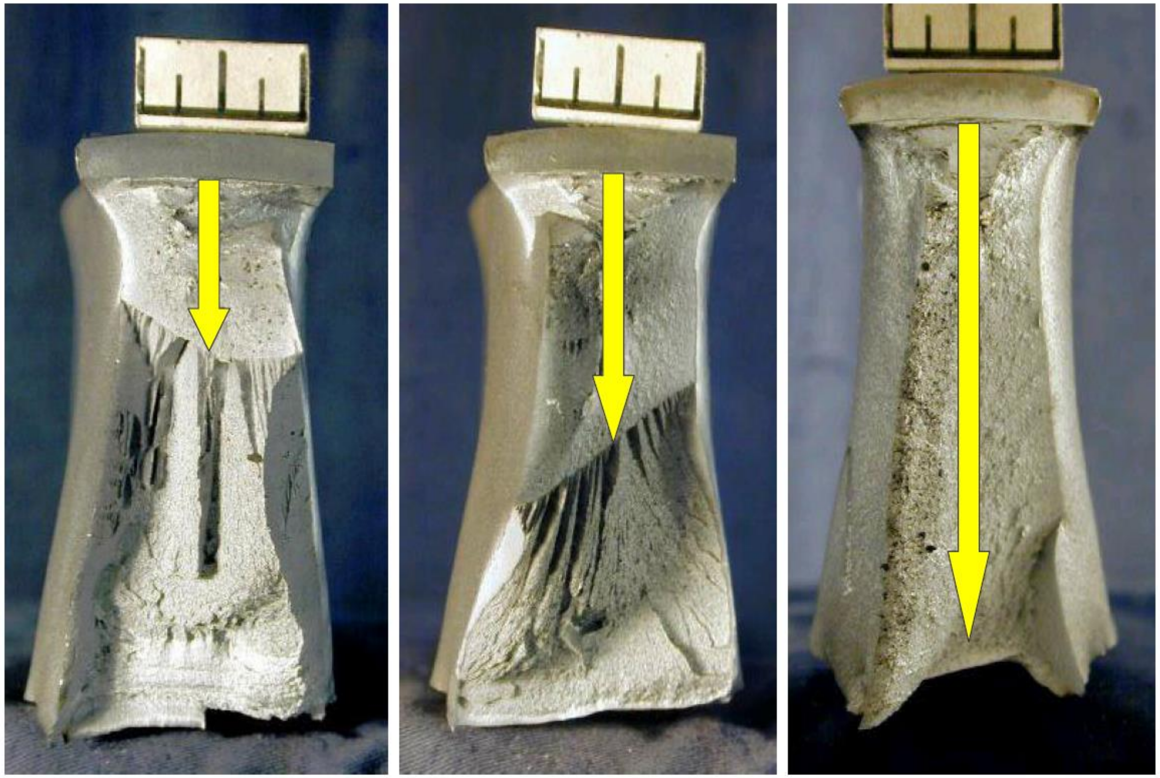
INVERSE FRACTURE IN DWTT SPECIMENS

There are two types of **abnormal fractures** seen in DWTT specimens of pipe steels. Their causes are different:

- ✓ **Cleavage fracture** follows immediately after the initiation of shear fracture at the notch of the DWTT specimen. It can be solved by inserting a static pre-crack, a fatigue pre-crack, an electron beam weld or a chevron notch instead of the conventional pressed notch;
- ✓ The specimen is subjected to **strong deflection** at the moment of impact, in addition to the consequent compression, which leads to the work hardening of the material located in the region opposite the notch, weakening it and eventually creating a second fracture front, which causes the **inverse fracture**.

The occurrence of inverse fracture does not necessarily lead to **material rejection**, but it prevents an adequate characterization of its toughness characteristics.

INVERSE FRACTURE IN DWTT SPECIMENS



Progressive Inverse Fracture

Normal Fracture

GRILL, R. VAI Continuous Casting and Hot Rolling Conference, Linz, June 2004.

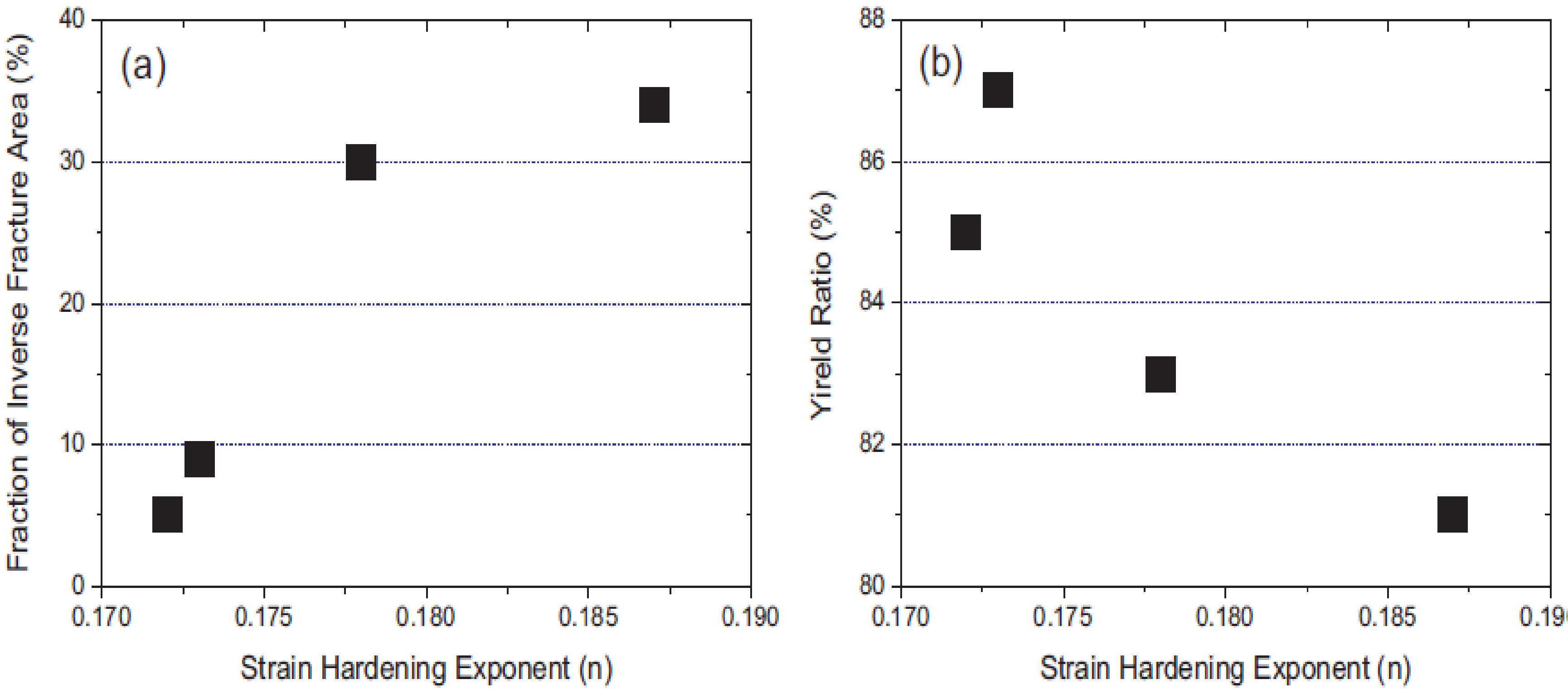
INVERSE FRACTURE IN DWTT SPECIMENS

Although the problem of abnormal fracture after DWTT tests has already surfaced for several decades, to date **all of its causes have not been determined** and no fully effective countermeasures have been proposed to suppress its occurrence.

However, some partial conclusions are available:

- ✓ The use of the so called **chevron notch** in the DWTT specimen decreases the occurrence of inverse fracture, but does not supress it completely. This specific notch reduces the energy need to crack nucleation, promoting the occurrence of brittle fracture.
- ✓ Eventually the use of **subsize DWTT specimens** is also helpful, as they reduce the degree of work hardening in the region impacted by the dart.
- ✓ Inverse fracture is more common in steels with **lower yield ratio**, as they tend to have a higher values of n-hardening coefficient, which present higher levels of embrittlement after impact.

INVERSE FRACTURE IN DWTT SPECIMENS



SUNG, H.K. et al. Materials Science and Engineering A, 541, 2012, 181-189

HARD SPOTS

It is not a new defect, as it was already detected in pipes manufactured in the U.S.A. during the 1950's and 1960's.

API 5L standard: "Any hard spot larger than 50 mm (2.0 in) in any direction shall be classified as a defect if its hardness exceeds 35 HRC, 345 HV10 or 327 HBW, based upon individual indentations".

Possible causes:

- ✓ **Fast cooling** after hot rolling;
- ✓ Burns during **arc welding**;
- ✓ **Strain hardening** associated to grinding marks.

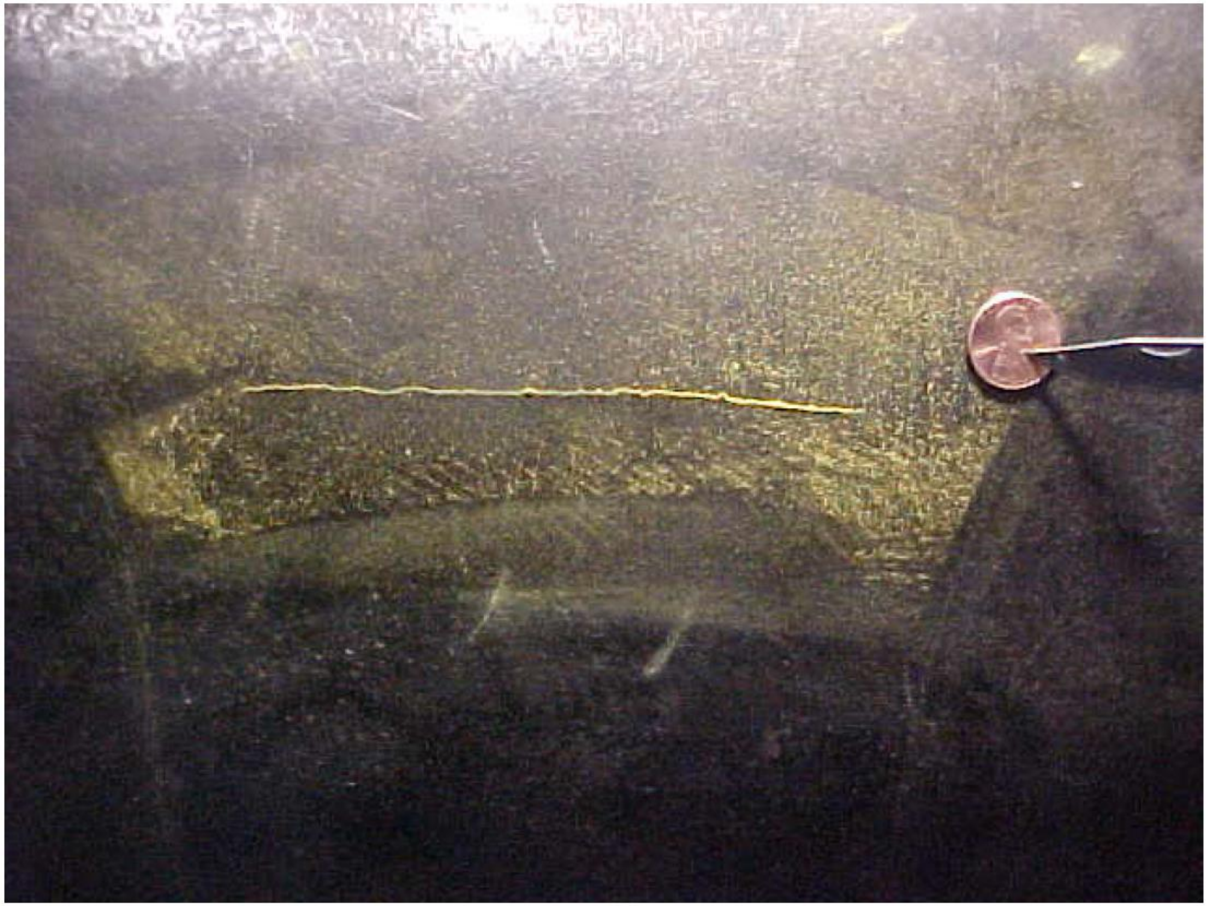
HARD SPOTS

Eventually hard spots still are detected during **vintage pipe non-destructive inspection** using pigs ("pipeline inspection gadget") with magnetic flux leakage sensors.

Their higher hardness make this regions **more prone to HIC**, requiring protection – e.g., protective coating or cathodic protection.

Originally the occurrence of this defect **was very rare** and limited to pipes produced before 1960 by a few American shops, so much so that the relevant standards never imposed massive hardness measurements on pipes or plates used in their manufacture.

HARD SPOTS



BELANGER, A. et al. Barker T. 10th International Pipeline Conference, ASME, Calgary, 2014.

HARD SPOTS

However, **a different version of this defect** was detected after the occurence of several leaks in a gas pipeline in the Kashagan field, near the Caspian sea, in 2014.

Such leaks apparently were due to sulphide stress cracking in **tiny areas of the pipe**, whose size was on the order of a **few tenths of a millimeter**, which unexpectedly presented **high hardness values**, both near welded joints and in the tube body.

This issue is very recent and there is as yet no information available on it, at least in the public literature. Possible causes:

- ✓ **Segregation**;
- ✓ **Scale layer thickness heterogeneity** during accelerated cooling;
- ✓ **Lack of control** during accelerated cooling.

Schruff, C. et al.Offshore Technology Conference – Brasil. Rio de Janeiro, October 2017, 9 p.

HARD SPOTS

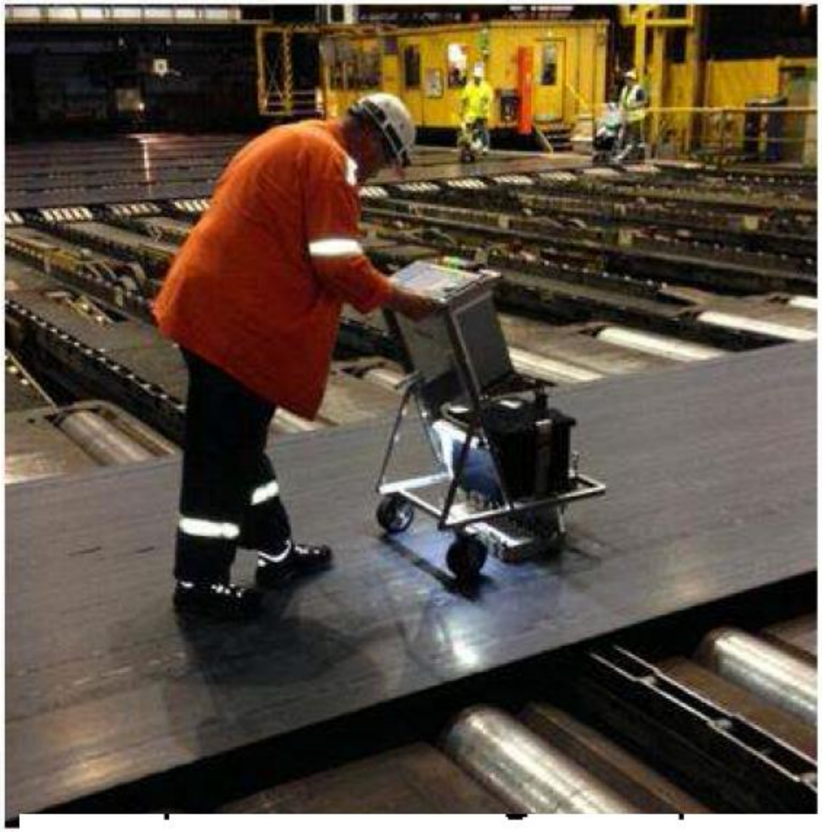
Apparently this defect is so small and rare – so it requires **100% inspection of the rolling stock** to be detected, which is impossible to be achieved manually.

Dillinger steelworks in Germany has developed a **non-destructive method** for the **massive** and **high resolution** measurement of hardness in rolling stocks, in a manner rather analogous to what is already done in the plate ultrasound analysis of internal soundness.

It is the so-called D-TECTor: Dillinger – Totally Eddy Current Detector, which determines **maps of plate hardness** using a magnetic test based on eddy currents.

Schneibel, G. et al. 19th World Conference on Non-Destructive Testing – WCNDT 2016, Munich, 2016, 8 p.

HARD SPOTS



Schneibel, G. et al. 19th World Conference on Non-Destructive Testing – WCNDT 2016, Munich, 2016, 8 p.

HARD SPOTS

Schneibel, G. et al. 19th World Conference on Non-Destructive Testing – WCNDT 2016, Munich, 2016, 8 p.

LOW Mn HTP STEEL FOR SOUR SERVICE

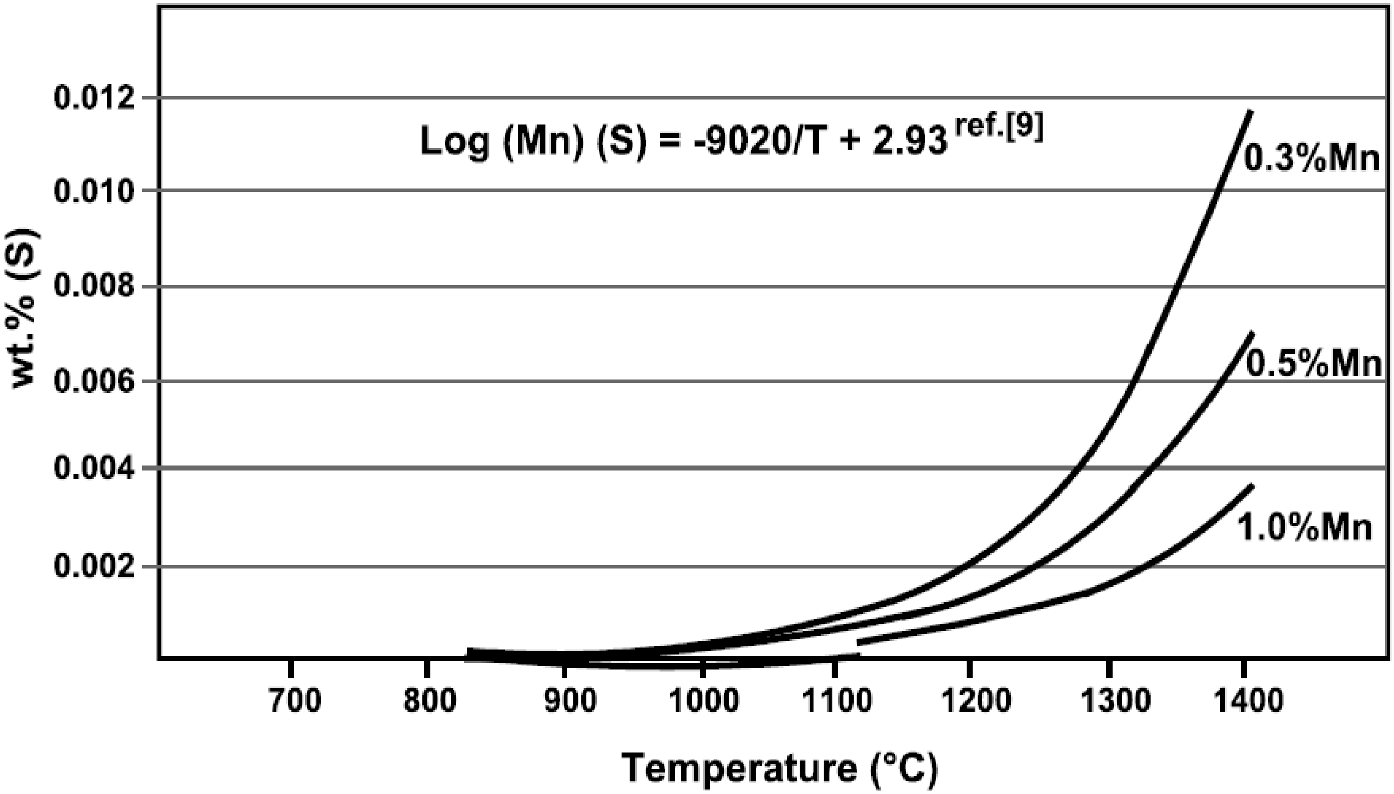
Pipes for sour service generally are made with **microalloyed steel with Mn amounts tipically in the 0.90-1.20% range**. Such Mn values are relatively high when compared to the rather low S amounts required for this application, typically below 0.001%.

Under such conditions there is the formation of **elongated inclusions of MnS**, which increase the susceptibility of the steel to HIC. In this case it is necessary to **globulize such inclusions** through the treatment of liquid steel with higher amount of Ca, leading to higher consumption of this material, steel projections and formation of excessive amount of inclusions.

Therefore, the **partial substitution of Mn by other alloying elements** presents potential advantages.

Gray, J.M. Microalloyed Pipe Steels for the Oil & Gas Industry. CBMM, Moscow, April 2013, 14 p.

LOW Mn HTP STEEL FOR SOUR SERVICE



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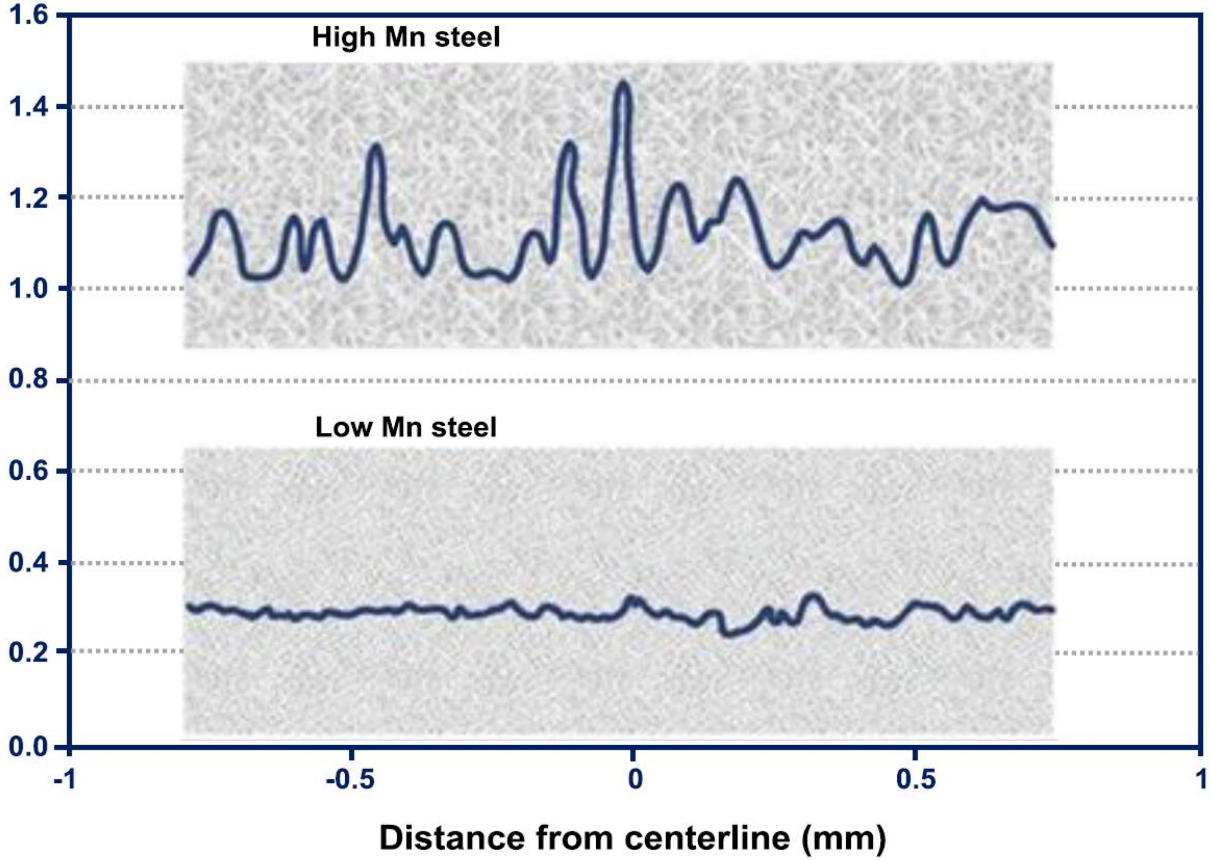

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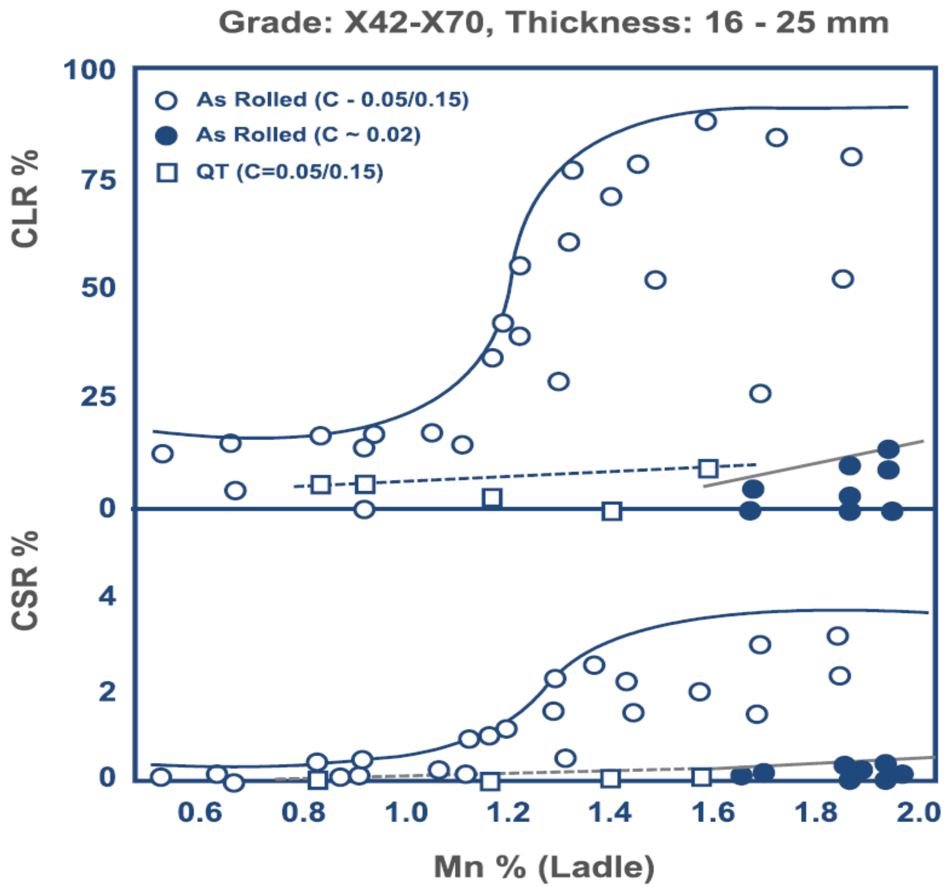

Gray, J.M. Microalloyed Pipe Steels for the Oil & Gas Industry. CBMM, Moscow, April 2013, 14 p.

LOW Mn HTP STEEL FOR SOUR SERVICE

From these findings it was proposed a **new concept of alloy design** for heavy plates intended for the manufacture of sour service pipes:

- ✓ **Reduction of slab central segregation**:
  - Reduced Mn amount;
  - C < 0.06% + Cr to promote solidification in the delta ferrite range, where the diffusion of alloy elements is fast;
  - Low casting speeds;
  - Use of soft reduction.
- ✓ **Solubility increase of MnS** through reduction of Mn and S amounts;
- ✓ **Plasticity decrease of MnS** through reduction of Mn:S ratio;
- ✓ **Addition of Nb and Cr** to compensate Mn amount reduction.

Gray, J.M. Microalloyed Pipe Steels for the Oil & Gas Industry. CBMM, Moscow, April 2013, 14 p.

LOW Mn HTP STEEL FOR SOUR SERVICE

Several steelworks tested this alloy concept, with Nb amount around 0.10%, with **good results** regarding mechanical properties and sour service requirements.

Gerdau Ouro Branco adjusted this new alloy design in order to **comply with API specifications** and is conducting tests to verify the best processing conditions that lead to materials that effectively meet the demands of **mechanical properties, weldability and sour service**.

CONCLUSIONS

This paper aimed to present and discuss briefly some of the **most important technological obstacles to be overcome** so that sour service plates continue to be an important material for applications related to the transport of hydrocarbons through pipelines:

- ✓ Improvement of DWTT test;
- ✓ Ensuring uniformity of hardness across the plate;
- ✓ Development of more efficient and economical alloys to meet the requirements of sour service.

Gerdau Ouro Branco has been actively working on these three development fronts in order to assume its role as the **preferred supplier of this material with maximum quality requirements**.

THANK YOU

FOR YOUR ATTENTION!

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