STEEL - MEETING THE NEEDS OF AN EVOLVING LINEPIPE INDUSTRY

David Langley – Industry Manager, Water, Oil & Gas, BlueScope Steel Limited
Frank Barbaro – Product Applications Manager, BlueScope Steel Limited
Chris Killmore - Product Design Manager, BlueScope Steel Limited
Jim Williams – Manager Metallurgical Technology, BlueScope Steel Limited

Steel - meeting the needs of an evolving linepipe industry
D. Langley, C. Killmore, F. Barbaro, J. Williams

ABSTRACT
The Australian natural gas transmission system is unique in that it is characterised by relatively small, fragmented markets located at long distances from the sources of supply. As a result Australian transmission pipelines are typically of smaller diameter (up to DN450) and relatively thin walled compared to international counterparts. Similarly the evolution of the design rules, construction practices and operating conditions to improve the economic efficiency and integrity of transmission pipelines has led to demanding requirements for Linepipe steel grades such as the following:

- A relatively high design pressure of 15MPa compared to 10MPa or less that is characteristically used in most parts of the world;
- The transmission of rich gas that places special demands upon fracture toughness;
- High strength levels typically X70 moving to X80; and
- An expected move from 72 to 80% design factor,

For approximately 40 years, BlueScope Steel has been actively pursuing developments in alloy design, steel making practices and hot strip processing, to achieve sufficient levels of strength, weldability and toughness to meet the ever-increasing demands of the Australian Linepipe Industry. Today, we are an active participant in the industry and have become a market leader in the development, manufacture and supply of specialty Linepipe steel grades. The recent initiatives and technical changes within the Linepipe industry are driving a more holistic approach to pipeline design.
01 INTRODUCTION

Since 1968, BlueScope Steel’s Port Kembla Steelworks has supplied over 1 million tonnes of steel plates and coils for manufacture into high-test Linepipe for the Australian oil and gas industry. Over that time, the strength and toughness requirements for pipeline steels have increased markedly. In particular, within the last twenty years, there has been a significant shift in the strength and toughness requirements of Linepipe steel grades. For example in 1973 the Jackson to Moonie pipeline was constructed from API 5L X52 pipe while in 1993 the Moomba/Jackson pipeline was the first in Australia to be constructed using API 5L X70. During this period the maximum operating pressures have risen from 6.8 MPa to 15.3 MPa. Since 1993, BlueScope Steel has supplied nearly 400,000 tonnes of X70 feed coil and it has now almost become the “standard” for major gas transmission pipelines in Australia.

These changes have been driven by the economic benefits of higher strength pipelines including:

1. Lower gas transportation costs,
2. Lower pipe procurement and transport-to-site costs and
3. Reduced welding costs due to smaller diameter and thinner wall.

The importance of achieving high strength in pipes without compromising field weldability was a major focus in the development of X70 grade ERW pipes and also laid the foundation for X80 grade development.

FIGURE 01 Evolution of PIPESTEEL™ grades at BlueScope Steel

©2010 BlueScope Steel is a registered trademark of BlueScope Steel Limited. ABN 16 000 011 058.
To meet the ever-increasing steel quality demands of pipeline steels, BlueScope Steel has invested significantly in the development of specialised plant facilities and steelmaking, casting and thermo mechanical rolling processes, a schematic of which is shown in Figure 2.

This paper outlines some aspects of steel production and the product development that has taken place at BlueScope Steel in response to market requirements over the past decade.

### TABLE 01

#### Major BSL Projects since 2000

<table>
<thead>
<tr>
<th>Year</th>
<th>Project</th>
<th>Pipe Size</th>
<th>Quantity (tonnes)</th>
<th>API 5L Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Thickness (mm)</td>
<td>Diameter (mm)</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>Peat Lateral</td>
<td>4.6</td>
<td>273.1</td>
<td>4,265 X60</td>
</tr>
<tr>
<td></td>
<td>Canberra Lateral</td>
<td>5.8 &amp; 8.4</td>
<td>273.1</td>
<td>1,778 X70</td>
</tr>
<tr>
<td></td>
<td>Barylalh</td>
<td>9.6</td>
<td>406.4</td>
<td>5,252 X70</td>
</tr>
<tr>
<td></td>
<td>Barrolka – Ballraa</td>
<td>8.6</td>
<td>323.9</td>
<td>5,789 X70</td>
</tr>
<tr>
<td>2001</td>
<td>Tasmania Natural Gas Pipeline</td>
<td>4.8 &amp; 7.8</td>
<td>168.3 &amp; 219</td>
<td>12,634 X65/X70</td>
</tr>
<tr>
<td></td>
<td>Roma Looping 5</td>
<td>5.6, 6.7, 8.0</td>
<td>406.4</td>
<td>10,880 X70</td>
</tr>
<tr>
<td>2002</td>
<td>SEAGAS Victoria to Adelaide Pipeline</td>
<td>7.7 &amp; 9.6</td>
<td>355.6</td>
<td>29,000 X70</td>
</tr>
<tr>
<td>2003</td>
<td>Kambalda to Esperance</td>
<td>4.0 &amp; 6.3</td>
<td>168.3</td>
<td>6,765 X46/X60</td>
</tr>
<tr>
<td></td>
<td>Telfer</td>
<td>6.3 &amp; 8.5</td>
<td>323.9</td>
<td>1,550 X60</td>
</tr>
<tr>
<td></td>
<td>BassGas</td>
<td>4.8, 6.4, 7.2</td>
<td>273.1</td>
<td>1,300 X65</td>
</tr>
<tr>
<td></td>
<td>Townsville/North Old Gas</td>
<td>7.2 &amp; 8.6</td>
<td>323.9</td>
<td>24,200 X70</td>
</tr>
<tr>
<td>2005</td>
<td>SESA</td>
<td>4.01 &amp; 6.77</td>
<td>219</td>
<td>2,311 X65</td>
</tr>
<tr>
<td></td>
<td>Mt Magnet</td>
<td>4.8, 5.6, 8.2</td>
<td>219</td>
<td>9,116 X52</td>
</tr>
<tr>
<td></td>
<td>Central Ranges</td>
<td>4.8 &amp; 6.1</td>
<td>219</td>
<td>9,558 X65</td>
</tr>
<tr>
<td></td>
<td>Braemar</td>
<td>9.65</td>
<td>406.4</td>
<td>6,000 X70</td>
</tr>
<tr>
<td>2006</td>
<td>Braemar II</td>
<td>9.65</td>
<td>406.4</td>
<td>9,000 X70</td>
</tr>
<tr>
<td></td>
<td>Comet Ridge</td>
<td>7.8 &amp; 9.4</td>
<td>355.6</td>
<td>9,000 X70</td>
</tr>
</tbody>
</table>

©2010 BlueScope Steel is a registered trademark of BlueScope Steel Limited. ABN 16 000 011 058.
BlueScope Steel considers that the major challenges in Linepipe design that we need to holistically review and respond to, include a combination of:

- The need to achieve the demanding pipe mechanical properties, in particular high strength,
- Steels that can be welded using the existing procedures of preheat free welding with cellulosic electrodes,
- Higher Charpy energy levels, due to the higher operating stresses, as well as to permit rich gas transportation and
- A low pipe yield strength range of less than 100 MPa above SMYS.

This combination of properties has required careful attention to alloy design, steel making and hot rolling practices.

2.1 Alloy design

The family of Linepipe steel grades offered by BlueScope Steel are based on a low Carbon (C), Manganese (Mn), Niobium (Nb) and Titanium (Ti) alloy design with a low overall total alloy content or carbon equivalent.

A key strategy in the development of higher strength Linepipe steel grades has been the use of a small Molybdenum (Mo) addition in conjunction with micro alloying with Niobium (Nb) and Titanium (Ti) components. The synergistic effect within this alloy system provides a very efficient strengthening capability. Accordingly, this alloy design allows the achievement of high pipe strength at lower carbon equivalents than traditional Niobium-Vanadium (Nb-V) steels particularly in heavier wall thicknesses. The Nb-V steels require relatively higher carbon equivalent designs, which can compromise their capability for preheat-free field welding with cellulosic consumables according to the guidelines specified in WTIA Technical Note 1 Recommendations. This weldability benefit is evident in Figure 3, which depicts typical average production data for some major projects over recent years. Moreover, the efficient strengthening capability of the Mo-Nb-Ti system provided the basis for the development of API X80.

Some other aspects of the alloy design include the use of calcium silicide treatment for the purpose of controlling non-metallic inclusion type and morphology and limiting the sulphur content. Low sulphur levels and non-metallic inclusion control improve both notch toughness and pipe ultrasonic performance.

**FIGURE 03** Relative strengthening capacity of Mo-Nb versus Nb/V micro alloying systems

![Graph showing relative strengthening capacity of Mo-Nb versus Nb/V](image)
2.2 Steel making and casting practices

The steel making process for production of Linepipe steel grades is complex and requires a considerable amount of rigour. Production of Linepipe steel grades requires the utilisation of special steel making and casting techniques that have been developed and refined over many years of high strength steel production. The main steelmaking processes involved are shown schematically in Figure 2.

A major evolution in steelmaking has been the development of secondary steel treatments to further refine the steel, accurately control alloy additions and to provide a high level of steel cleanness in respect to non-metallic inclusions. Such secondary steelmaking practices include injection of the steel with calcium silicide powder and degassing the steel by cycling it under a vacuum. In particular, these post steelmaking refining treatments enable the achievement of low sulphur levels, reduced levels of dissolved gases such as hydrogen, fine adjustments to the composition, particularly the micro alloying elements and condition the steel to control the non-metallic inclusion type, volume and morphology.

The tight compositional control achieved by utilising vacuum degassing ensures a narrow range of carbon equivalent that ensures consistent weldability. Figure 4 shows the tight control over carbon equivalent made possible by vacuum degassing. Vacuum degassing also allows for fine adjustments to be made to the chemical composition, achieve the required hydrogen content, and to minimise the content of non-metallic inclusions.

During the continuous casting process ceramic shrouds and inert gas are used to protect the liquid metal stream and avoid oxidation of the steel. This aids compositional control, steel cleanness and mechanical property control.

FIGURE 04  Carbon equivalent performance on the last three (3) X70 pipeline projects produced at BlueScope Steel Port Kembla Works

![Carbon equivalent performance chart](chart.png)
2.3 Thermo mechanical processing

Control of the entire rolling process from slab reheating through to coiling is essential to ensure the appropriate strength and fracture toughness requirements are achieved in the hot rolled strip. The refinement of the ferrite grain size of the final strip simultaneously increases the strength and toughness of the steel. Hence, one of the main aims of the thermo mechanical controlled processing of the slab to strip is to maximize the ferrite grain refinement.

The slabs are reheated to the rolling temperature in a walking beam furnace. The slab extraction rate and furnace zone set points are specified in order to ensure uniformity of heat and therefore, efficient dissolution of micro alloys. The roughing mill pass schedule is designed to give reductions that will maximise austenite grain refinement.

The entry temperature and total finishing mill reduction are specified in order to control the metallurgical conditioning of the austenite as dictated by the mechanical property requirements. Similarly, the strip finish rolling temperature is specified as part of the total package of austenite grain refinement whilst still being above the austenite – ferrite transformation temperature. Accelerated cooling is applied to the strip immediately upon exiting the finishing mill using modern rod-laminar cooling technology to achieve very high cooling rates to enhance the steel strengthening potential. The amount of cooling applied and the coiling temperature are specified to produce as fine a ferrite grain size as possible whilst still enabling strengthening of the ferrite by the micro alloys.

The thermo-mechanical rolling conditions have a major influence on the control of the final strip properties. However, strip strength variations for these steels have proven to be rather small in the range of finish rolling and cooling parameters normally selected for production conditions. This makes Mn-Mo-Nb-Ti steels ideally suited to the achievement of narrow strength ranges across large project orders.1

2.4 Pipe properties

When the hot rolled strip is converted into ERW pipe, the pipe forming and sizing strains can significantly modify the pipe yield strength by virtue of the Bauschinger effect and work hardening behaviour. Pipe yield strengths can be either significantly increased or decreased as a result of this (Figure 5). Even within pipe production runs, variation in pipe forming conditions can cause scattering of the strip to pipe strength shift from rolling to rolling resulting in variation in the range of mechanical properties produced.

BlueScope Steel has refined its steel design processes to ensure that the variation in strip to pipe strength relationship is carefully managed. Steel microstructure is a factor in this behaviour and underlines the critical interrelationship of alloy design and thermo mechanical processing factors. The close working relationship between BlueScope Steel and domestic pipe makers means that the correlations between strip and pipe properties are well understood. This results in a more consistent pipe product that provides the best possible outcome for the industry.

![Figure 05: Relationship between strip and pipe ring expansion yield strength](image)

©2010 BlueScope Steel is a registered trademark of BlueScope Steel Limited. ABN 16 000 011 058.
03 RECENT DEVELOPMENTS

3.1 Maximum pipe yield strength range

There is a growing emphasis from pipeline designers for a controlled range of pipe strengths, such as SMYS + 100 MPa. The reason for this is to ensure overmatching strength of girth weld metal to provide adequate protection of weld metal defects in the event of longitudinal in-service displacement of the pipe in regions of unstable terrain.

This requirement presents two challenges to the steel producer. Firstly, a tight distribution of YS for any one grade and strip thickness, as 100 MPa is about the limit to which mechanical properties can be contained within in a production environment, where numerous process variables can influence the strength of the strip. Secondly, the achievement of the targeted value for the average of the population is also critical in order to meet the requirements for all resultant pipes to be in a range of SMYS+100MPa, as the former issue does not permit any leeway for the positioning of the strength. Moreover, if multiple strip thicknesses are included, as can be required with major pipelines, then the overall yield strength range can increase to about 120 MPa. Hence, it would be necessary to produce more than one composition to comply with a narrow 100 MPa range. This can add complexity and costs to production where only relatively small quantities are required in some sizes. Therefore, engaging BlueScope Steel in the design process will ensure that the careful design and control of the steel chemical composition and an intimate knowledge of the effects of rolling parameters are considered when finalising the Linepipe steel grade for a project. This is critical when it comes to achieving tight control of strip and subsequently pipe strength.

At BlueScope Steel, empirical predictive strength modelling has been used to verify that appropriate strip strength is achieved at each thickness; thereby, helping to ensure that strip yield and tensile strength is optimised within the range required by the pipe maker. This in turn allows the pipe maker to select the appropriate strip strength to ensure pipe properties are within the desired yield strength range. Overall, the accuracy of these empirical equations has proven to be more than adequate to achieve the required level and range of strip strengths (Figure 6).

To further aid in meeting the strength range requirements for the industry, BlueScope Steel has expanded its range of Linepipe steel grade designs to provide smaller strength increments between grades. This assists in positioning the pipe strength range appropriately. Figure 7 shows the benefits of tight control over both steel making and hot rolling parameters enabling production of hot rolled coil feed for pipe production with small mechanical property variation.

**FIGURE 06** Predicted vs. actual YS using empirical models for 19 major X70 projects (Mo-Nb-Ti steels) with sheet thickness in range of 4.8-9.7mm

<table>
<thead>
<tr>
<th>Predicted Value (MPa)</th>
<th>Actual Value (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>560</td>
<td>560</td>
</tr>
<tr>
<td>570</td>
<td>570</td>
</tr>
<tr>
<td>580</td>
<td>580</td>
</tr>
<tr>
<td>590</td>
<td>590</td>
</tr>
<tr>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>610</td>
<td>610</td>
</tr>
</tbody>
</table>

©2010 BlueScope Steel is a registered trademark of BlueScope Steel Limited. ABN 16 000 011 058.
3.2 Relativity of yield and tensile strength
The yield and tensile strength relativities required by API 5L PSL2 present some particular challenges. Figure 8 demonstrates how the allowable range for both yield and tensile strength reduces with increasing the API 5L grade. At the same time, the yield strength converges on the maximum allowable tensile strength. Achieving the increase in yield strength whilst not exceeding the maximum allowable tensile strength can be challenging.

Additionally, higher strength Linepipe steel grades in pipe sizes requiring large forming strains, will further increase in yield strength on conversion from strip to pipe. This can make it difficult to produce coil with sufficient tensile strength without exceeding the maximum allowable yield strength in the pipe, particularly given that the strength increase during forming is more pronounced for yield strength than for tensile strength. This is further exacerbated by requirements for tighter yield strength ranges than those given in PSL 2, such as SMYS +100Mpa.

3.3 Yield/tensile strength ratio
A critical design factor for BlueScope Steel to manage is the notion of limiting YS/TS ratio. Modern low C steels that rely on micro alloying and thermo mechanical processing to achieve strength, tend to have higher YS/TS ratios than higher carbon steel grades. The lower carbon levels reduce the tensile strength, whilst ferrite grain size refinement and precipitation hardening increase the yield strength, leading to a higher yield/tensile strength ratio.

YS/TS is further increased by the strain aging, which occurs during pipe coating. A move to YS/TS based design, as has been proposed in the revision of AS2885, would require the steel maker to produce steels which exhibit more strain hardening capacity in the base steel. Whilst not insurmountable, this would require a revision of the current alloy designs in order to meet this requirement whilst still maintaining the current level of weldability using the existing welding practices as employed by the Australian line pipe industry.
3.4 Fracture toughness

Traditionally, steelmakers have sought to control toughness by restricting sulphur levels to be below 0.005\% (or even lower limits) depending on the specific requirements of a pipeline. Some steel manufacturers, as an additional countermeasure, have the capability to achieve complete sulphide shape control using Ca injection processes. Such practices involve significant capital and operating costs. The effect of sulphur level on the Charpy toughness is shown in Figure 9.
The current low carbon, micro alloyed, fine-grained Linepipe steel grades as described above, are capable of achieving the fracture toughness requirements necessary to avoid ductile fracture propagation with sulphur levels up to 0.005%. However, where pipelines are required to transport ‘rich’ gas, higher levels of ductile fracture propagation resistance (Charpy energy) are required. Together with the proposed increase in design factors from 72% to 80% SMYS, and a shift to higher strengths such as X80, the required level of Charpy energy to avoid ductile fracture propagation is yet to be quantified. Similarly, seam weld line toughness becomes a requirement of the revised AS2885 Pt 1. This then challenges the steel producer as to the technical feasibility of producing steels with sufficiently high Charpy energy values.

BlueScope Steel is currently investigating alternate alloy designs to meet these demanding needs within the current steel making facility constraints. Work is still in its early infancy, however, it is anticipated that this approach will be transferable from X42 through to X80 type steels. Flow-on benefits can be expected in the area of inclusion control and therefore weld line toughness.

**04 CONCLUSIONS**

1. Australian pipelines have evolved to the extent that X70 has now become the “norm”.

2. The pipe used for these pipelines has been largely produced in Australia from Mo-Nb-Ti steels that give excellent properties with narrow property ranges.

3. Recent developments in the pipe line industry with the inception of API 5L PSL2 and the planned revision of AS2885 Pt 1 have presented some particular challenges to the steel designers, in particular maximum yield and tensile strength limits, YS/TS ratio and fracture toughness requirements.

4. BlueScope Steel is continually seeking innovative solutions to improve on steel design to meet these evolving needs of the Linepipe industry in Australia.

**05 REFERENCES**


Notice: BlueScope Steel Limited (BSL) makes no representation or warranty (either express or implied) as to accuracy or suitability, for any purpose, of the information contained in this paper. Any reliance on the information provided is at your sole risk. BSL and its related entities shall not be liable, and you agree to indemnify BSL, for any claim, loss or damage resulting from the use of or reliance on, the information or part thereof, by you or any third party to whom you supply the information. You should seek independent professional advice on the information provided.

This paper is protected by copyright law under and the Copyright Act 1968. No part of this paper may be reproduced without the express permission of BlueScope Steel Limited.

This paper was presented at the 2006 APIA conference Alice Springs.