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TECHNICAL APPLICATION BRIEFING

The Birth and Evolution of HTP (High Temperature Processed) Linepipe Steels

THE CHANGING LANDSCAPE

Significant long distance infrastructure projects, to expand the world's oil and gas distribution network, have been steadily emerging across the continents. The pipe needed for such initiatives is now often required to be of the higher strength API 5L X70 or X80 grades and also tends to be of much larger diameter with increased wall thickness. These combined changes reflect the need to quickly transport increasing volumes of hydrocarbons at higher pressures.

Evolution of Conventional Metallurgical Design

Over the decades, the metallurgical design of steels for linepipe has changed dramatically [1]. In the early years carbon, in conjunction with manganese, was the cheapest way to achieve the modest strengths required and it was not uncommon to encounter X52 and X60 steels with carbon up to 0.26 percent. Even into the early 1970's carbon levels were still surprisingly high, both for X60 and X65. However, there was a price to pay for this and both pipe toughness and, more significantly, weldability were adversely affected.

Through the remainder of the 1970's and early 1980's most significant linepipe projects only required X65 or X70 steels [2] and, whilst carbon levels were progressively reduced, the real 'revolution' came later, when by the mid 1980's carbon levels first fell consistently below 0.12 percent and the plate or skelp for pipe manufacture was predominantly produced in conjunction with thermomechanical controlled processing (TMCP).

During this transitional period, most X65/X70 alloying strategies still relied on conventional niobium-vanadium alloying or the sporadic application of niobium-vanadium with or without the addition of molybdenum. Italsider however, also demonstrated in 1980 that a low carbon nickel-niobium (0.14 to 0.16 percent) variant, suitable for at least the X70 level, could be utilized and that particularly outstanding drop weight tear test and weldability results could be achieved.

During the 1990's the technical demands for X80 began to increase as there was a growing requirement to move larger volumes of hydrocarbons at higher pressures, often over longer distances, and various suppliers such as STELCO, in Canada, refined the original low carbon, niobium–molybdenum approach to produce what are now referred to as 'acicular ferrite' X80 steels [3].

However, unpredictable fluctuations in the prices of molybdenum and vanadium during earlier decades soon refocused attention back on the potential benefits of the low carbon, 0.10 percent niobium route pioneered back in 1972. It was realized that X80 strength could be reliably achieved without molybdenum and vanadium, adding as required, modest alloying with chromium and/or copper and nickel [4].

A Step Back in Time

As the demand for even higher strength and tougher pipe intensified, the overriding importance of lowering carbon to enhance field weldability became paramount. However, the scope to employ low carbon is, to a considerable degree, limited in the presence of vanadium as the latter element is actually more effective as a strengthener at higher carbon levels. Therefore, since most of the steels referred to previously often contained combinations of niobium and vanadium, together with other alloying additions to achieve increased strength, this presented an opportunity to revive and re-awaken interest in an existing, but not widely appreciated, technology that actually provides the optimum technical and economic solution for all strength levels above X65.

By the turn of the century, carbon levels had been lowered into the 0.08 to 0.10 percent range but were still not conducive to the most effective use of niobium to improve properties, and it was known that if carbon could be reduced below 0.05 percent then significantly higher levels of niobium, up to at least 0.11 percent, could then be dissolved during reheating and utilized to dramatic advantage. This class of steel, colloquially referred to as HTP (High Temperature Processed) therefore, steadily became the focus of attention.

The fundamental metallurgical research that underpins our ability to use very low carbon (<0.05 percent) linepipe steels with niobium content up to 0.12 percent for X70 and X80 strength levels, is now some 50 years old and the modern HTP concept itself was actually developed nearly 40 years ago. The latter involves the use of carbon levels usually below 0.05 percent and niobium levels of up to 0.11 percent with judicious additions of chromium, as required, 'tailored' to meet the exact strength requirements. Such compositions were then, and still are, economically attractive and provide so many additional benefits to rolling mills, including reduced holding times, lower loads etc, that they represent an optimum solution for plate or coil supplied for high strength, large diameter pipe manufacture up to at least the X80 level [5].

Low carbon facilitates the more complete dissolution of niobium during reheating which in turn maximizes the sequential beneficial effects of niobium during high temperature processing. Such effects are well documented but the retardation of recrystallization at higher finishing temperatures is key to reducing rolling mill loads while the precipitation hardening and depression of austenite transformation temperature combine to produce leaner steels less reliant on other alloying elements.

Conventional ferrite pearlite, niobium–vanadium steels are often finish rolled in the 710 to 830 degrees C temperature range, whereas for the low carbon bainitic HTP steels, 840 to 910 degrees C, or even higher, is more typical. Only a dramatic reduction in carbon can ensure that sufficient niobium is in solution, prior to the start of rolling, to derive all of the benefits alluded to previously. Niobium is the only element that truly facilitates rolling at higher than normal temperatures.

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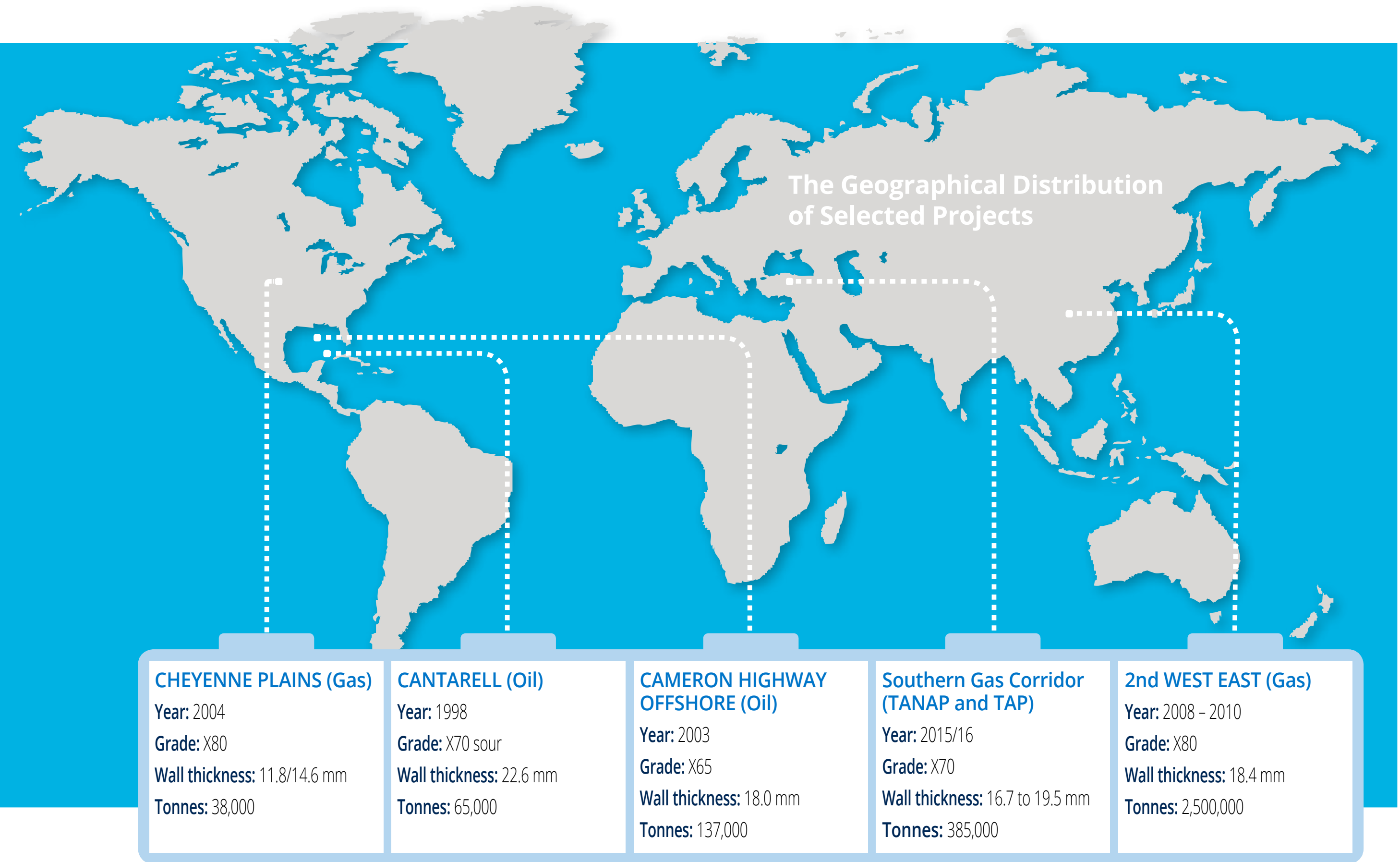

Full Scale Trial and Commercialization

In 1983 a full-scale demonstration heat of the chromium-niobium HTP option was sponsored by CBMM and produced by Sumitomo in Japan [6]. Slabs were processed in a systematic collaborative exercise through the rolling mills of thirteen different companies in North America, Europe and the former USSR. The steel had an average carbon level below 0.03 percent with niobium at about the 0.10 percent level. This highly successful venture also provided proof of concept for the use of this class of steel for sour service applications, as it was produced with a sulfur level below 0.001 percent and with modest copper, chromium and nickel additions.

It was the success of the North American rolling trials which finally provided the incentive for the first commercial application of the 'pure' HTP concept, when in 1997/8 the heavy gauge, 36 inch, Cantarell X70 sour gas (pH=5) pipeline was laid in the Gulf of Mexico on behalf of Pemex [7,8]. A few years on, and following the success of the 2003 El Paso Energy Partners Cameron Highway 380 mile subsea oil pipeline, also in the Gulf of Mexico, the technical and political climate was just right for the very first significant X80 pipeline in the USA. This was the Cheyenne Plains Project constructed by the Colorado Inter State Gas Company and 38,000 tonnes (82 miles) of 36 inch diameter pipe was produced by the Napa Pipeline Corporation of California using the low carbon, 0.10 percent niobium-chromium philosophy [9].

Both the Cantarell and Cheyenne Plains material evaluations demonstrated significant processing and weldability advantages in direct comparison with conventional alloying routes for X70/X80. With the technology rapidly increasing in popularity, ArcelorMittal adopted the HTP philosophy in 2008 to supply half of the steel for the 1,323 mile Kinder Morgan (Rockies Express) 42 inch natural gas pipeline, which now supplies over seven million American homes each year [10].

However, perhaps the most significant commercial breakthrough came when the Chinese built on the success of the Cantarell and Cheyenne Plains Projects to develop a Chinese National Petroleum Corporation (CNPC) specification for their thick wall X80 2nd West East trans-China high pressure gas pipeline, which consumed two and a half million tonnes of HTP class low carbon, 0.10 percent niobium-chromium material from Baosteel [11].

More recently, ArcelorMittal have supplied a very similar analysis, without chromium, for the X70 Turkish, Tosçelik, section of the Trans Anatolian Project (TANAP), some 310,000 tonnes, and a further 75,000 tonnes for the Trans Adriatic Project (TAP).

1960's
Research provides stimulus for development of low carbon steels with niobium levels up to at least 0.12 percent.

1971
'Pearlite free' low carbon X70 steel with niobium and molybdenum commercially applied in Canada.

1972
First 'Arctic' grade X80 molybdenum free linepipe steel produced based on a low carbon, 0.10 percent niobium concept.

1980
Low carbon, nickel X70/X80 developed in Italy with 0.14 to 0.16 percent niobium with outstanding properties.

1983
Full scale demonstration heat of the chromium-niobium HTP steel produced in Japan, sponsored by CBMM, and evaluated internationally.

1990's
Further refinements of low carbon pearlite free steels now commonly referred to as acicular ferrite or bainitic ferrite steels.

1998
The Pemex Cantarell Project uses the pure HTP concept for a Gulf of Mexico, thick wall X70, sour service (pH=5) pipeline.

2003
HTP concept pipe also used for the Cameron Highway crude oil project in the Gulf of Mexico, the largest offshore pipeline system in the USA.

2004
Cheyenne Plains - First onshore X80 pipeline in the USA and a significant portion of the gas line utilizes HTP low carbon, niobium-chromium steel.

2008
Half of the steel for the Kinder Morgan 1,323 mile gas pipeline uses HTP steel similar to that used for Cheyenne Plains.

2010
China adopts HTP technology and applies it successfully in their 5,500 mile X80, 2nd West East high pressure gas pipeline.

2015/16
310,000 tonnes of X70 low carbon, niobium HTP steel supplied for a key section of the TANAP gas pipeline project, and a further 75,000 tonnes to the TAP project.

2017+
Low manganese, 'sour service' variants of HTP steels and optimized 'OHTP' steels with carefully tailored chemical compositions will become available.

Advantages of HTP Steels and Track Record

Avoiding lower temperature austenite processing regimes decreases mill loads, increases productivity and decreases wear on equipment. Additionally, niobium retards recovery, recrystallization, and in solid solution lowers the austenite to ferrite transformation start temperature. The higher finishing temperatures virtually eliminate the undesirable heavily textured microstructures associated with lower temperature rolling and this leads to superior mechanical property combinations and improved resistance to ductile fracture propagation. This metallurgical 'miracle' uniquely provides a bainitic ferrite microstructure, which provides the steel with high strength and toughness and enhanced weldability.

HTP steels already have an extensive reliable service record since the 1970's, both onshore and offshore, as the timeline diagram opposite demonstrates [12].

The geographical distribution of selected projects is also illustrated on the map at the top of the previous page.

Image courtesy of CRC-Evans

International Standards and the Future

National and international standards, which dictate steel chemical composition for linepipe projects, have not all adapted quickly enough to fully embrace the HTP technology, but that has not prevented enlightened end users, guided by entrepreneurial individuals, preparing proprietary specifications, utilizing the new technology to their specific advantage. The CNPC and other significant project examples have already been cited.

Now, at last, increased awareness of the HTP technology is leading to the ongoing revision of the world's most influential API and ISO standards for pipe plate or strip and in the not too distant future carbon levels in higher strength niobium bearing linepipe will be severely restricted.

Looking Forward

There can be no doubt that HTP technology is already revolutionizing the industry and is contributing, in an increasingly important way, to facilitate the efficient transport of hydrocarbons from source reserves across the globe to their expanding market place. The 'Revolution' continues, and can only increase in pace as the benefits of the alloying approach become more widely appreciated.

Finally, two exciting new opportunities are on the horizon for the HTP alloying philosophy. Firstly, by optimizing the titanium, nitrogen and niobium contents to maximize technical benefits for specific plate or strip producers there is the prospect of even greater property enhancements and this year may see the first full production trials of OHTP ('optimized') steel for particularly demanding applications. Secondly, and already publically unveiled, is a family of HTP steels with greatly reduced manganese levels (down to 0.25 percent) which can achieve at least X65 level strength with significantly increased sour gas resistance across a wide range of pH conditions [13]. Manganese contributes to center-line segregation of both itself and sulfur in linepipe steels and its removal appears to promise major benefits. As with the conventional HTP steels, niobium and chromium are the strengthening substitutes for the dramatically reduced manganese.

The HTP story is compelling and there is an irresistible 'wind of change' blowing which, if harnessed, could deliver significant technical and economic advantages that the linepipe industry would be ill-advised to ignore.

Further Information

Further information can be obtained at: technology@cbmm.com

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