IPC2010-31014

INFLUENCES OF FINAL PIPE FORMING PROCESS BY ROLL BENDING METHOD ON THE MECHANICAL PROPERTIES OF SAW PIPES

轧辊弯曲终成形工艺对埋弧焊管力学性能的影响

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ABSTRACT

There are three main methods and process for forming pipes from plates "Roll Bending", "JCOE" and "UOE". In all of the above mentioned ways part of the pipe will remain flat, and can not achieve the desired curvature of the pipe. These areas are generally at the two longitudinal edges of the open seam pipes.For obviation of these flat areas at the longitudinal edges of the pipe, the pre forming machines for "JCOE" and "UOE"processes, and the post bending machine for "the Roll Bending" process are used. In the post bending machine the final shape of the pipes is determined based on the rate of the machine hoist pressure and the spaces between the rolling dies.These parameters can have various effects on the mechanical properties of the final welded pipes. In the research that has been conducted at SAFA Rolling & Pipe Mill Company, the amount of hoist pressure and the final shape of the open seam pipes in the post bending machine, and their influences on the mechanical properties of the welded pipes, have been investigated herein.

IPC2010-31021

EFFECT OF FRACTURE SPEED ON DUCTILE FRACTURE RESISTANCE – PART 2: RESULTS AND APPLICATION

断裂速率对延性断裂抗力的影响：第二部分-结论和应用

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ABSTRACT

One of the many aspects of natural gas pipeline design and material selection is the consideration of propagation and arrest of high-speed axial ductile fracture in the line pipes. Understanding the material ductile fracture behavior is essential for establishing an integrated fracture control plan. This is particularly important for pipelines of high design pressures utilizing large-diameter and high-grade line pipes. The procedure of Battelle Two-Curve Method (TCM) has been most commonly used in ductile fracture analysis in the prediction of fracture speed and minimum arrest toughness for

axially running cracks. In the past decades, discussions and research have been in that the TCM approach, among with others, could not accurately predict either fracture speed or minimum arrest fracture toughness for high-grade pipes, and with pipe grade increasing the prediction errors are getting larger. Recent research work at TransCanada indicates that for a better prediction of pipeline ductile fracture, understanding the basic material mechanical behavior and its fundamental fracture mechanism is essential. One of the important findings of the work is that pipe material fracture toughness is not a constant as being commonly treated, rather the fracture toughness, in terms of both steady-state CTOA and steady-state DWTT fracture energy is fracture speed dependent, being decreasing with increasing fracture speed. Corresponding modifications have been made to the traditional TCM by introducing speed-dependent fracture toughness. The improved model gives much better predictions in both fracture speed and toughness for high grade pipes.

This paper presents recent work at TransCanada, together with its industry partner Engineering Mechanics Corporation of Columbus (EMCC), on high-speed pipe-material fracture testing technique (using the modified back-slot DWTT specimen) and high-grade material testing data. The test data supports the predictions of early published work on speed-dependent fracture toughness. The fracture speeds obtained from the modified back-slot DWTT specimens were very close to actual full-scale pipeline ductile fracture speeds and this in turn enhanced the applicability of the modified TCM model.

IPC2010-31022

EVALUATION OF DOUBLE JOINTING GIRTH WELDS OF HIGH GRADE LINE PIPES

高钢级管线管双面环焊缝的评价

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ABSTRACT

Double jointing is an effective approach for pipeline construction in terms of both welding productivity and consistent weld quality as a result of a controlled working environment. However, the high heat input associated with the submerged arc welding (SAW) process used for double jointing must be considered with respect to the material properties of both heat affected zone (HAZ) and the weld metal of double jointing welds. This is particularly important for strain-based design pipeline applications utilizing high grade pipe, such as X80 and X100.

High grade pipe materials achieve their strength as a result of controlled rolling practices that produce a fine grained steel. High heat input welding results in an increased grain size in the heat-affected zone, and often results in

softening and a detrimental effect on the properties of the welded joint. The softening effect in the HAZ will potentially cause highly localized deformation, which is undesirable in conditions where strain-based design is applicable. Understanding the material mechanical property in double jointing welds, and approaches for measuring mechanical behavior of such welds are required in order to meet the increasing demand for double jointing in the pipeline industry.

This paper presents an approach that has been used in TransCanada for understanding and evaluating double joint welds of high grade pipes. The approach has been implemented into detailed testing protocols, data analysis procedures and requirements, and has been proven to be an effective and practical means for double jointing evaluations.

IPC2010-31027

Decompression Wave Speed in Rich Gas Mixtures at High Pressures (37 MPa) and Implications on Fracture Control Toughness Requirements in Pipeline Design

高压下（37Mpa）富气混合物的纵波速率及对管线设计中断裂韧性控制要求的意义

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Abstract

Measurements of decompression wave speed in conventional and rich natural gas mixtures following rupture of a highpressure pipe have been conducted. A high pressure stainless steel rupture tube (internal diameter = 38.1 mm, and 42 m long), has been constructed and instrumented with 16 high frequency-response pressure transducers mounted very close to the rupture end and along the length of the tube to capture the pressure-time traces of the decompression wave. Tests were conducted for initial pressures of 33-37 MPa-a and a temperature range of 21 to 68 oC. The experimentally determined decompression wave speeds were compared to both GASDECOM and PIPEDECOM predictions with and without non-equilibrium condensation delays at phase crossing. The interception points of the isentropes representing the decompression process with the corresponding phase envelope of each mixture were correlated to the respective plateaus observed in the decompression wave speed profiles. Additionally, speeds of sound in the undisturbed gas mixtures at the initial pressures and temperatures were compared to predictions by five equations of state, namely BWRS, AGA-8,

Peng-Robinson, Soave-Redlich-Kwong, and GERG. The measured gas decompression curves were used to predict the fracture arrest toughness needed to assure fracture control in natural gas pipelines. The rupture tube test results have shown that the Charpy fracture arrest values predicted using GASEDCOM are within +7 (conservative) and –11% (non-conservative) of the rupture tube predicted values. Similarly, PIPEDECOM with no temperature delay provides fracture arrest values that are within +13 and -20% of the rupture tube predicted values, while PIPEDECOM with a 1 oC temperature delay provides fracture arrest values that are within 0 and –20% of the rupture tube predicted values. Ideally, it would be better if the predicted values by the equations of state were above the rupture tube predicted values to make the predictions conservative but that was not always the case.

IPC2010-31303

THE APPLICATION OF QUANTITATIVE X-RAY DIFFRACTION (RIETVELD REFINEMENT) IN CHARACTERIZING THE MICROSTRUCTURE AND PRECIPITATES IN MICROALLOYED STEELS

定量 X 射线衍射（Rietveld 修正法）在刻画微合金钢微观结构和析出物中的应用

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ABSTRACT

Quantitative X-ray diffraction (the Rietveld Method) was used to quantify both the crystallite size (diffracting length) and precipitate size in several grades of microalloyed steels. The crystallite size calculated from diffraction profiles obtained from the rolling faces of X80 and X100 was found to decrease with decreasing coiling temperature. Quantitative X-ray diffraction analysis was also conducted on precipitate residues extracted (by matrix dissolution) from a Grade 100 microalloyed steel. A mean precipitate size of 4.8 nm was calculated for the fine (Nb, Mo,Ti, V) carbides observed in this steel. This value compares favourably with precipitate size measured using TEM and SANS analysis.

IPC2010-31057

J AND CTOD ESTIMATION PROCEDURE FOR CIRCUMFERENTIALLY CRACKED PIPES BASED ON FULLY-PLASTIC SOLUTIONS

基于全塑性解的周向开裂钢管的J积分和CTOD评估方法

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ABSTRACT

This work provides an estimation procedure to determine the *J*integral and CTOD for pipes with circumferential surface cracks subjected to bending load for a wide range of crack geometries and material (hardening) based upon fully-plastic solutions. A summary of the methodology upon which *J* and CTOD are derived sets the necessary framework to determine nondimensional functions *h*1 and *h*2 applicable to a wide range of crack geometries and material properties characteristic of structural, pressure vessel and pipeline steels. The extensive nonlinear, 3-D numerical analyses provide a large set of solutions for *J* and CTOD which enters directly into fitness-for-service (FFS) analyses and defect assessment procedures of cracked pipes and cylinders subjected to bending load.

IPC2010-31071

RESEARCH AND PROSPECT ON RELATIONSHIP BETWEEN MICROSTRUCTURE CHARACTERISTICS AND STRENGTH-TOUGHNESS OF HIGH GRADE PIPELINE STEEL

对高钢级管线钢微观结构特征和强韧性之间关系的研究和预测

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ABSTRACT

The strength property of high grade pipeline steel has been obviously improved with the rapid development of the constructing of oil and gas pipelines. And the excellent strength-toughness matching of pipeline steel is very important. The major affecting factor on strength-toughness of pipeline steel is microstructure characteristic. In this paper, the research status of pipeline steel microstructure characteristic including effective grain size, non-metallic inclusions and banded structure is summarized at home and abroad. In addition, the shortcomings of former research on the relationship between microstructure characteristics and strength-toughness are also analyzed for this pipeline steel. On this basis, a solution is put forward to investigate the characterization of effective grain size and micro-mechanical behavior of inclusions and banded structure with the method of electron backscatter diffraction and the method of SEM in situ observation. And the necessities and feasibilities of the solution are discussed.

IPC2010-31073

KEY QUALITY ASPECTS FOR A NEW METALLIC COMPOSITE PIPE: CORROSION TESTING, WELDING, WELD INSPECTION AND MANUFACTURING

新型金属合成管的主要的质量关注点：腐蚀检测，焊接，焊缝检测及加工

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ABSTRACT

The composite pipe system, known as XPipe™,uses high-performance adhesives to manufacture a
metallic composite pipe.

Both technical development and a robust manufacturing quality system are required to ensure the safe use of such novel technology. Several aspects are discussed in this paper. Firstly, the use of ultrahigh
strength martensitic steels in a buried,cathodically protected environment requires an understanding of their susceptibility to hydrogen embrittlement. A series of slow strain rate and constant load tests was performed under polarized conditions to establish any reduction in ductility over samples tested in air. The results are presented and implications for their use in such a system are discussed.

Secondly, although the technology to perform quality welds in thin walled austenitic materials using
automated orbital techniques is well established, weld inspection by radiographic techniques is not preferred
due to the continuous nature of the process and safety considerations. However, the inspection of such welds by ultrasonic techniques is challenging due to the coarse grained nature of the austenitic welds and the thinness of the liner, well below the 6mm normally considered the minimum for conventional weld inspection. Therefore, Automated Ultrasonic Testing (AUT) requires optimized ultrasonic techniques. AUT capabilities and recommendations towards an optimal inspection concept will be discussed in this paper.

Thirdly, the manufacture of the liner, ultra-high strength steel strip and adhesive into the XPipe™
composite pipe requires a robust manufacturing control system, which maintains traceability of the incoming materials and controls and records all the essential parameters during pipe production. This is achieved using a sophisticated SCADA system, using feedback from a variety of sensors.

IPC2010-31076

MEASUREMENT OF CTOA OF PIPE STEELS USING MDCB AND DWITT SPECIMENS

采用改良的双悬臂试样（MDCB） 和 DWTT 试样测定管线钢的裂纹尖端张开角

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ABSTRACT

Two types of specimen for crack tip opening angle (CTOA) measurement have been investigated for pipeline applications,i.e., the modified double cantilever beam (MDCB) (at NIST) and the drop-weight tear test (DWTT) specimen (at CANMET).Results of effects of specimen types, thicknesses and loading rates on CTOA are summarized and discussed. The main observations include: (i) For both MDCB and DWTT specimens tested at quasi-static loading rate, crack front tunneling (i.e., with a deep triangular crack-tip shape) was present in high-strength steels; (ii) For DWTT specimens, CTOA values measured optically at the surface were significantly higher than those from the simplified single-specimen method (S-SSM) and those measured at mid-thickness [on sections cut using electric discharge machining (EDM)]; and (iii) CTOA values from surface measurement of MDCB specimens were comparable to those derived from S-SSM of DWTT specimens, but the surface values of DWTT were higher than those of MDCB specimens.

KEYWORDS: CTOA, MDCB, DWTT, ductile fracture,fracture toughness, pipe steel, test method

IPC2010-31078

QUALIFICTION STRATEGY FOR FAST-PIPE™ FOR HIGH PRESSURE GAS PIPELINES

用于高压输气管线的FAST-Pipe™钢管的质量方针

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ABSTRACT

Because major reserves for natural gas are often remotely located from potential market, its transportation requires larger diameter pipes operating at high pressures. In order to reduce cost, high strength steels (≥ X80) have been advanced to reduce the wall thickness of the pipeline and thus lower materials, transportation and construction costs. However, producing large diameter high pressure pipelines of these steels creates significant challenges that can only be met by very few steel suppliers. This paper presents the qualification results of an alternative technology that will reduce cost even more than high strength steels while using conventional steel such as X70. This technology, which is designated as Fiber Augmented Steel Technology Pipe (FAST-Pipe™),

involves hoop winding dry glass fibers over conventional steel pipes (e.g. X70) to provide the required high pressure capacity. The steel thickness is selected to mainly satisfy axial and bending load requirements. Following a proof-of-concept of the FAST-PipeTM, a detailed qualification program was developed based on a decision and risk analysis strategy that incorporates key elements of the industry technology qualification guidelines (DNV RP A203 and API 17N). The qualification program involved addressing fifteen design, construction and operational parameters. The paper presents the FAST-PipeTM concept, discusses its advantages and summarizes the results of its qualification program.

IPC2010-31106

ADVANCED TECHNOLOGIES FOR MANUFACTURING HIGH STRENGTH SOUR GRADE UOE LINE PIPE

制造高强度酸性UOE管线管的先进技术

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ABSTRACT

X70 grade large diameter UOE linepipe steel for sour service has been manufactured stably by optimizing the continuous casting process, controlling the shape of inclusions and decreasing coarse precipitates. It is confirmed that the HIC and SSC resistance are good enough for severe sour conditions to apply. These higher strength linepipe steels for sour service are useful for the offshore and deep-sea pipelines. Additional improvements of HIC and SSC resistances are needed for manufacturing thicker and higher strength UOE linepipe steels for sour service. Optimizing alloying elements and ACC process are very important for the additional improvements of HIC and SSC resistance. In addition, the HIC evaluation method should be revised in order to match applied field conditions.

IPC2010-31137

EFFECT OF DEPOSIT COMPOSITION ON THE MECHANICAL PROPERTIES AND CRACKING TENDENCY OF CELLULOSIC-COVERED SMAW WELD DEPOSITS

化学沉积对纤维素焊条手工电弧焊焊缝力学性能和断裂倾向的影响

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ABSTRACT

This investigation utilizes test electrodes manufactured with boron at different levels (including no boron). The design of these electrodes is identical with the exception of the intentional changes highlighted. Gapped bead on plate (GBOP) testing is used to determine the relative propensity of the electrodes for weld metal cracking. Test electrodes are also evaluated for deposit composition, CVN impact toughness, strength, and hardness on pipe joints. This work also uses a non boron-containing test electrode whose deposit composition has been modified such that its carbon equivalent is the same as one of the boron-containing electrodes. This serves to separate the influence of the specific element boron from the influence of general carbon equivalent/hardenability on the tendency for cracking.

The results indicate that the effect of changes in boron and carbon equivalent over the range tested and in this specific electrode design is very slight. In most cases, the effect is not significant when compared to the amount of variation observed in the testing. In essence, the signal was lost in the noise. In terms of susceptibility to hydrogen assisted cold cracking (HACC) - the area of most concern - there appear to be other factors that are much more influential than those tested. If the goal is to minimize the cracking sensitivity of cellulosic weld metal, simply eliminating the use of boron is not the answer. More work is required to identify these other factors and quantify their effect.

IPC2010-31153

EFFECTS OF M/A ISLANDS MICROSTRUCTURE CHARACTERISTIC ON MECHANIC PROPERTIES OF HIGH GRADE PIPELINE STEEL

M/A岛状微观组织特性对高钢级管线钢力学性能的影响

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ABSTRACT

The microstructure characteristic of martensite/austenite(M/A) islands of

X80-1#, X80-2#, X100-3#, X100-4# steel pipelines come from different manufacturer were investigated by OM and SEM contrastively, and the influence of M/A islands microstructure characteristics of pipelines were studied combining with tests of mechanic properties. The result shows that the effect of the M/A islands volume fraction, average dimension, form and distribution on the material strength, yield ratio and toughness were distinct. When the M/A islands distribute uniformly with small size and spherical or crossed strip form, under the certain volume fraction, the pipeline steel exhibits excellent strength-toughness matching.

IPC2010-31155

MICROSTRUCTURE EVOLUTION IN THE HAZ OF GIRTH WELDS IN LINEPIPE STEELS FOR THE ARCTIC

极地用管线钢环缝热区的微观结构的变化

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ABSTRACT

A critical aspect of building pipelines to transport natural gas will be development of suitable high strength steels and new economic welding procedures, e.g. dual torch welding, without compromising the pipeline's structural integrity during its in-service performance. The objective of this project is to predict the microstructure and mechanical properties of the weld heat affected zone (HAZ) of an X80 linepipe steel as a function of its temperature-time history. The approach taken involves a combination of experimental techniques and advanced modelling approaches. On the experimental side, dual-torch weld trials for assessment of spatial and temporal variations of temperature in the HAZ were conducted. To simulate and investigate the microstructure evolutions in the HAZ, i.e. precipitate dissolution, austenite formation, grain growth and decompositions, Gleeble thermo-mechanical simulations were performed. These simulations include rapid heating and cooling tests at rates of up to 1000 °C/s. Notably, real-time monitoring of austenite grain growth was possible by using a novel laser ultrasonic technique. Further, bulk samples were produced using the Gleeble

adopting the experimentally determined temperature time history. These bulk specimens were subsequently subjected to tensile and fracture resistance tests. A concise overview of these novel experimental activities, highlighting new insights, is presented and challenges associated with the measurements are discussed.

IPC2010-31166

EFFECT OF SEPARATION ON DUCTILE CRACK PROPAGATION BEHAVIOR DURING DROP WEIGHT TEAR TEST

落锤撕裂试验中分离对延性断裂扩展行为的影响

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ABSTRACT

The demand for natural gas using LNG and pipelines to supply the world gas markets is increasing. The use of highstrength line pipe provides a reduction in the cost of gas transmission pipelines by enabling high-pressure transmission of large volumes of gas. Under the large demand of highstrength line pipe, crack arrestability of running ductile fracture behavior is one of the most important properties. The CVN(Charpy V-notched) test and the DWTT (Drop Weight Tear Test) are major test methods to evaluate the crack arrestability of running ductile fractures. Separation, which is defined as a fracture parallel to the rolling plane, can be characteristic of the fracture in both full-scale burst tests and DWTTs. It is reported that separations deteriorate the crack arrestability of running ductile fracture, and also that small amounts of separation do not affect the running ductile fracture resistance. This paper describes the effect of separation on ductile propagation behavior. We utilized a high-speed camera to investigate theCTOA (Crack Tip Opening Angle) during the DWTT. We show that some separations deteriorate ductile crack propagation resistance and that some separations do not affect the running ductile fracture resistance.

IPC2010-31172

Study of Influence Factors on the CTOA Toughness Values by Experiment/Simulation Method

通过试验/模拟的方法研究CTOA韧性值的影响因素

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ABSTRACT

Although the crack-tip-opening angle (CTOA) has been widely recognized as an efficient fracture criterion for modeling stable crack growth and instability during the fracture process, the variation of its toughness value with many different kinds of factors changing for specific material during steady crack extension has been the focus of attention, such as specimen thickness, crack tunneling, notch shape,displacement rate, etc.

At first, the present paper reviewed a variety of fracture parameters assessing the stable crack extension for ductile fracture toughness of pipelines steels or aluminum alloys. It was summarized that a few of test techniques and calculation methods available for determination of CTOA toughness, and the development of relative testing standards.Furthermore, the focus for this paper was to discuss a variety of influence factors of the CTOA toughness values in accordance with the results from the CTOA testing and finite element simulation of X70 and X80 steel specimens with different ligament thickness and the relative published articles.

To compare the different CTOA values obtained by using direct surface methods and indirect methods from finite element analyses (FEA), CTOA toughness values of X70 and X80 pipeline steel were measured with a modified double-cantilever beam (MDCB) specimen in the servo-hydraulic uniaxial test machine. The gauge thicknesses included 4, 8 and 10 mm. The result of this study showed that critical CTOA values decreased with gauge thickness increasing. It was found that the computed surface CTOA in 3-D finite element analysis was generally lower than direct surface CTOA in the experimental measurement.

KEYWORDS

Crack-tip-opening angle (CTOA); crack-tip-opening displacement (*δ5*); stable crack extension; crack-extension resistance; thin-walled structures; pipeline; R curve

IPC2010-31176

PREDICTION OF RAPID DUCTILE CRACK EXTENSION AND ARREST BY AN ANALYTICAL APPROACH

通过一种分析方法预测快速延性断裂扩展和止裂

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ABSTRACT

Under special circumstances a fast propagating crack can be triggered in pipelines by just a small local damage. In order to assess the safety with regard to this type of catastrophic failure, an analytical model was established to describe the process of large ductile tearing mathematically. Using a simplifying kinematical model and the hypothesis that the tearing fracture process is governed by a constant CTOA, the total energy dissipation rate can be quantified and compared to the available fracture energy. Since the Charpy

fracture energy KV is often the only available toughness-related material parameter of existing pipelines, the toughness parameters used in the model, particularly CTOA, has to be determined from KV. This was achieved by using the same 2-parameter model of ductile tearing to analyse the fracture process in bending. A closed form relationship was obtained between the minimum pressure required for fast ductile crack propagation and the system and material parameters. It could be shown that rapid ductile tearing requires the hoop stress to exceed a certain limit, which depends on the geometrical parameters of the pipeline and KV of its material. The analysis was verified by comparison of the results with the experimental data of full- scale burst tests available in the literature. Unlike empirical correlations, the derived analytical formula seems to be universally valid, regardless of pipe dimensions or steel grades.

IPC2010-31180

STUDY ON TENSILE PROPERTY AND STRAIN AGEING BEHAVIOR OF X100 LINEPIPE

X100管线管应变时效行为和拉伸性能的研究

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ABSTRACT

A series research programs and industrial trials of X100 linepipe have been launched by CNPC so as to build an X100 trial in China for long-distance gas pipeline in the coming years. In present paper, tests have been conducted on 20.6mm×1016mm diameter Grade X100 linepipe. The microstructures, tension properties will be presented. In order to investigate the influence of anti-corrosion coating process on the performance of pipe, strain aging tests in lab have been carried out as well. It is found that testing method, tensile specimen size and sampling location had a noticeable effect on the testing results. The difference is also observed between the flattened strap specimen and round bar. The influence of time, temperature and pre-strain amount of aging tests on the shape of S-S (stress-strain) curve, tension tests results,yield ratio of pipes are presented as well.

IPC2010-31191

TOWARDS A NUMERICAL DESIGN TOOL FOR COMPOSITE CRACK ARRESTORS ON HIGH PRESSURE GAS PIPELINES

用于高压输气管线的合成止裂器的数字设计工具

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ABSTRACT

One of the major challenges in the design of ultra high grade (X100) high pressure gas pipelines is the identification of a reliable crack propagation strategy. Ductile fracture propagation is an event that involves the whole pipeline and all its components, including valves, fittings, flanges and bends. Recent research results have shown that the newly developed high strength large diameter gas pipelines, when operated at severe conditions (rich gas, low temperatures, high pressure),may not be able to arrest a running ductile crack through pipe material properties. Hence, the use of crack arrestors is required in the design of safe and reliable pipeline systems.

A conventional crack arrestor can be a high toughness pipe insert, or a local joint with higher wall thickness. Steel wire wrappings, cast iron clamps or steel sleeves are commonly used non-integral solutions. Recently, composite crack arrestors have enjoyed increasing interest from the industry as a straightforward solution to stop running ductile cracks. A composite crack arrestor is made of (glass) fibres, dipped in a resin bath and wound onto the pipe wall in a variety of orientations.

In this paper, the numerical design of composite crack arrestors will be presented. First, the properties of unidirectional glass fibre reinforced epoxy are measured and the micromechanic modelling of composite materials is addressed.Then, the in-use behaviour of pipe joints with composite crack arrestors is covered. Large-scale tensile tests and four point bending tests are performed and compared with finite element simulations. Subsequently, failure measures are introduced to predict the onset of composite material failure. At the end, the ability of composite crack arrestors to arrest a running fracture in a high pressure gas pipeline is assessed.

IPC2010-31206

Modeling Approaches for Anisotropic Material Properties of High Strength Steel Pipelines and the Effect on Differential Settlement

高强度管线钢各向异性材料特性建模方法及其对不均匀沉陷的影响

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ABSTRACT

High strength steel (HSS) pipelines exhibit anisotropic behavior; the yield stress in the circumferential direction is higher than the yield stress in the longitudinal direction. In addition, the shape of the stress vs. strain curve is distinctly different. The circumferential stress vs. strain curve has a sharp yield point, while there is no distinct yield point in the longitudinal direction. Most of the research done in the past on the behavior of high strength steel was based on the isotropy assumption. The material behavior of high strength steel pipelines cannot be satisfactorily modeled based on this assumption. Different material models are available which can take into account this plastic anisotropy of high strength steel.They can be grouped into two categories. First, there are models which treat material as intrinsically anisotropic [15]. And, there are other models which can take into account plastic anisotropy as being caused by the load history. In this paper, the plastic anisotropy is modeled using the second approach.

Freezing and thawing of the discontinuous permafrost in the northern regions of Canada causes differential settlement of pipes. This induces significant longitudinal stress in addition to the circumferential stress due to internal pressure. It is very important to accurately model the differential settlement of the pipe and the stresses caused by it. In this paper the differential settlement is modeled using beam elements in Abaqus. The behavior of the pipeline under differential settlement loads is investigated using three different material models. The first two are assuming that the material behaves according to the traditional isotropic plasticity model, once with the longitudinal and another time using the circumferential stress strain curve as basis for the model. The third one is using an analytical virgin material stress strain curve based on the kinematic hardening plasticity model which predicts the appropriate behavior in each direction. The displacement versus the reaction force of the pipe is obtained for pipes without internal pressure and for pipes subjected to internal pressure causing a circumferential stress that is 80% of the specified minimum yield strength of the material. It is found that the response of the pipe is different for different material models. The response based on the analytical virgin material stress strain curve is closer to the response based on the longitudinal stress strain curve when the pipe is not subjected to internal pressure. But, when the pipe is subjected to internal pressure, the response using the analytical virgin material curve is closer to the circumferential stress strain curve.

IPC2010-31209

APPLICATION OF B-ADDED LOW CARBON BAINITE STEELS TO X80 UOE LINE PIPE FOR ULTRA LOW TEMPERATURE USAGE

加硼低碳贝氏体钢在超低温条件用X80级UOE管线管的应用

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ABSTRACT

Demand for high strength line pipes is increasing because of the reduction in natural gas transportation costs of pipelines.Low temperature toughness is required for high strength line pipes. Reduction in manufacturing cost of high strength linepipes is also required in an environment where alloying cost is increasing. To meet these requirements, boron (B) addition is extremely useful because the addition of very small amounts of B remarkably improves the strength and low temperature toughness. B-added low carbon bainite (LCB) line pipes with American Petroleum Institute (API) grade X60 to X80 have been developed for several decades [1-2]. B-added LCB steels have excellent low temperature toughness,however, it is challenging to achieve excellent crack initiation resistance and crack arrestability for ultra low temperatures such as -60oC. In particular, it is very difficult to achieve both excellent Drop Weight Tear Test (DWTT) properties of base metal, and excellent Charpy V-Notched (CVN) properties of seam welds in heavier wall thickness of X80 UOE linepipe.Metallurgical concepts such as the optimum chemical compositions, Thermo Mechanical Control Process (TMCP) conditions and seam weld conditions of B-added LCB steels with API grade X80 for ultra low temperature have been proposed in order to achieve the excellent mechanical properties even in a low manufacturing cost. Based on this concept, excellent DWTT properties of base metal and CVN properties of the seam welds of API grade X80 line pipe with 25mm thickness down to –60oC were obtained.

IPC2010-31219

A STUDY ON THE RESIDUAL STRESS AND FRACTURE BEHAVIOR OF PIPELINE GIRTH WELDS JOINING PIPES OF DIFFERENT STRENGTH)

不同强度管线管对接的环焊缝接头残余应力和断裂行的研究

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Key Words: Residual Stress, Fracture Behavior, Girth Weld, Strength Mismatch, Natural Gas Pipeline

ABSTRACT

The following cases of girth welded region between pipelines having

different base strength were considered. The pipeline shows different fracture behavior from girth welded pipeline between similar materials due to strength mismatch and residual stress distribution.

Investigation about the residual stress distribution and fracture behavior of pipeline having girth welds of the different base metals (X70/X65 and X70/X42) with different material property has performed using finite element analysis.

The effect of mismatched material property on girth weld region is negligible when shape of pipeline is similar. The assessment for occurance of crack on girth weld region with pipes with material property mismatched can be replaced by that of the similar pipes with low strength on the point view of conservation.

IPC2010-31227

HIGH STRENGTH HEAVY PLATE OPTIMISED FOR APPLICATION IN REMOTE AREAS AND LOW-TEMPERATURE SERVICE

针对偏远地区和低温条件的高强度厚板的优化

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ABSTRACT

The last decades have seen a steady increase in the demand for high-strength linepipe steels. These offer the most economical option to transport large gas volumes at high pressures from remote areas to the market. Since the beginning of the 1980's, high strength heavy plates, pipes and pipe bends were developed and produced at Salzgitter Mannesmann Grobblech GmbH and EUROPIPE. Since these days, these products were steadily improved for example in terms of toughness and weldability. As gas resources in increasingly hostile environments are developed, the requirements with regard to deformability and low-temperature toughness have gained growing significance. This is a strong focus of materials development around the world.

Modern high-strength heavy plates used in the production of UOE pipes are generally produced by thermomechanical rolling followed by accelerated cooling (TMCP). If accelerated cooling starts above the ferrite-austenite transformation temperature, this processing route results in a microstructure that consists predominantly of bainite. The combination of high strength and high toughness of these steels are a result of the microstructure realised by TMCP and are strongly influenced by the rolling and cooling conditions. Classical light-optical characterisation of the microstructure of these steels is at its limits because the size of the observed features is too small to allow reliable quantitative results. Therefore alternative methods have to be used to obtain a better understanding of the influence of processing conditions on the

microstructure.

The mechanical properties of high strength plates produced at Salzgitter Mannesmann Grobblech (MGB) and of material rolled using a laboratory rolling mill at the Salzgitter Mannesmann Forschung (SZMF) was characterised with special emphasis on low-temperature toughness. The microstructure was investigated using the electron backscatter diffraction (EBSD) method. With this method, it is possible to gain quantitative information related to features of the microstructure and relate these to the mechanical properties of the plate material. It was found that a variation of the processing conditions has a direct influence on parameters that are accessible through the EBSD method and correlates with mechanical properties. These results can be used as valuable input for the definition of the processing window for heavy plate production depending on the required plate properties.

IPC2010-31232

INFLUENCE OF THE FORMING OPERATIONS ON THE YIELD STRESS MEASURED ON PIPE

成型操作对钢管上测量的屈服应力的影响

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ABSTRACT

The yield stress of pipes is measured among purposes to assess the resistance of the pipe to the internal pressure of the fluid.Unfortunately, it is not possible to sample a straight specimen in the hoop direction, and therefore the pipe has to be flattened prior to testing. In the present investigation, different materials were tested in tensile - compression mode in order to provide data for a kinematic hardening model. Based on this experimental data set, a model was built to take into account several features of the material behavior (presence of yield point elongation, strain hardening, etc…) and the processing route (longitudinal or spiral seam weld, expander, hydrotest…). Pipe production was also sampled at different moments (base material, after leveling, after pipe forming, after hydrotest). The testing program included tensile testing and ring expansion tests. The results show that the model gives a prediction in good correspondence with the experimental results. The model also reproduces several experimental facts, like for example the presence of a yield point elongation on the base material and its absence on the flattened pipe sample. Finally, the model is compared with an industrial database containing different steel grades (from grade B to X80) and different ratios of wall thickness over diameter (t/OD) ratios. The difference of yield stress between coil and pipe is predicted on this database with an accuracy of 20MPa.

IPC2010-31233

HFI-WELDED PIPES – WHERE ARE THE LIMITS?

高频感应焊管：禁区在哪里

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ABSTRACT

The high frequency induction (HFI) method for production of longitudinally welded pipes was introduced in the early sixties. Initially HFI-welded pipes served more or less only as a low-cost product for standard applications without increased requirements. The growing demand for energy in North America, Europe and the Far East over the last decades has resulted in an increase in the exploration and exploitation of natural gas and oil resources in remote environments under aggravated conditions. This led to more demanding requirements on the mechanical-technological properties of the pipes. Additionally, an accelerated increase of safety awareness can be observed for operation of pipelines, in order to prevent environmental or population damage.Salzgitter Mannesmann Line Pipe GmbH (MLP) coped with the growing responsibilities by having optimized the HFI-welding process over the last decades, in order to produce top quality pipes suitable for practically all requirements.The modifications to this manufacturing process have resulted in a smaller scatter in geometrical pipe parameters and in optimisation of the relevant mechanical-technological properties. This led to HFI-welded pipes which, besides the aspect of lower cost, now offer several further advantages, compared to seamless pipes or SAW-pipes, and enables the use for economical and safe applications.

The present paper deals with the compliance of the progressive application requirements, using HFIwelded pipes from Salzgitter Mannesmann Line Pipe works. It will be focussed on the increased production capabilities and mechanical-technological properties of diameters up to 24 ” (610.0 mm) and 1 ” (25.4 mm) wall thickness, as well as higher API 5L and 5CT grades up to X70M for sour-service and weldable P110, respectively.As there is also an increasing tendency to use steel pipes for structural applications which require an enhanced spectrum of dimensions in recent years, the paper will provide details of the upgraded product portfolio for structural hollow sections (circular, square and rectangular) at MLP.

IPC2010-31235

FULL-SCALE BURST TEST OF HYDROGEN GAS X65 PIPELINE

X65输氢管线全尺寸氢气爆破试验

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ABSTRACT

Full-scale burst test of X65 UOE linepipe, with 559mm outer diameter and 13.5mm wall thickness, pressurized at 16MPa by hydrogen gas was conducted. A 735mm long crack was introduced by explosive shaped charge over circumferential weld. The cracks were initiated and propagated in the both directions. The propagated crack lengths were 600mm and 270mm. J integral resistance curves were obtained from drop-weight as well as quasi static tests for the tested pipe material which was subjected to hydrogen charging. The tested steel showed little change in the resistance curves under realistic charging condition. Numerical simulation model of dynamic crack propagation, coupled with gas decompression behavior considering gas escape from opened crack, showed that an initiated crack was arrested at shorter distance in hydrogen gas pipelines than in methane gas pipelines, primarily due to earlier gas decompression in the former. The present results, together with the earlier full-scale burst tests conducted by the authors, demonstrated that hydrogen gas pipelines can be operated safely by using modern high-strength and high-toughness steel linepipes.

IPC2010-31237

HEAVY WALL SEAMLESS LINE PIPE X70 – X80 FOR SOUR SERVICE APPLICATIONS

酸性服役条件用厚壁x70-x80钢级无缝管线管

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ABSTRACT

The continued shift of exploration and production to deep water fields will require the industry to develop alternative pipe solutions to cope with the challenging demands of these exploration regions. Because of the complexity of exploration conditions in deep water fields, e.g. high pressures, low temperature and sour reservoirs, higher grades and heavier wall thickness in

combination with low temperature toughness and suitability for sour service are required.

The Vallourec&Mannesmann Tubes's alloying concept for line pipe steels based on low carbon concept [1] was extended to grades X70 and X80 with wall thicknesses up to 75mm. In this paper the latest results on industrial studies on high strength heavy-wall steels manufactured by seamless hot rolling and subsequent quench and temper treatment are presented. The work is a part of the development program for high performance heavy wall seamless pipes for special applications such as J-lay collars, buckle arrestors and risers. Mechanical properties, advanced metallographic examinations, results of the sour service resistance and weldability are reported.

IPC2010-31240

Weld Metal Hydrogen Cracking in Transmission Pipelines Construction

输送管线建设中的焊缝金属氢致开裂

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ABSTRACT

Developments of high strength steels for natural gas pipelines have been in the forefront of steelmaking and rolling technology in the past decades. However, parallel to such developments in steel industry, the welding technology especially with regards to SMAW process which is still widely used in many projects has not evolved accordingly. Decreasing carbon equivalent has shifted the tendency of hydrogen cracking from the HAZ to the weld metal. Hydrogen cracking due to its complex mechanism is affected by a range of interactive parameters. Experience and data gained from field welding of pipeline construction projects indicated that weld metal hydrogen cracking is related to welding position as it occurs more in the 6 o'clock position of pipeline girth welds. In this research an attempt is made to open up the above observation in order to investigate the contributory factors such as welding position and welding progression in terms of diffusible hydrogen and possibly residual stress considerations. It was observed that transverse cracks produced in laboratory condition may not be detected by radiography.But, the higher tendency for cracking at 6 o'clock position was confirmed through bend test. It is shown that more hydrogen can be absorbed by the weld metal in the overhead position. It is shown that welding progression may also have a

significant effect on cracking susceptibility and it is proposed that to be due to the way that weld residual stresses are developed. The observations can have an important impact on planning for welding procedure approval regarding prevention of transverse cracking in pipeline girth welds.

IPC2010-31250

MICROSTRUCTURE – PROPERTY RELATIONSHIP IN 22MM THICK X80 COIL SKELP

22mm厚X80卷板微观组织和性能之间的关系

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ABSTRACT

The progress in the development of heavy gauge X80 linepipe steel on coil at ArcelorMittal was recently rewarded with a 6000 ton commercial order for the production of 21.6mm wall thickness spiral welded pipe. The further product development is concentrating on the improvement of the impact toughness at low temperatures. Research is currently focussing on the relationship between the mechanical properties and the microstructure of the steels. In the present study, two industrially hot rolled X80 steels with thickness 21.6mm were investigated. The steels had the same chemical composition but were processed with different parameter sets in the hot strip mill. The two resulting low-carbon bainitic microstructures were composed predominantly of quasi-polygonal ferrite and globular bainitic ferrite / bainitic ferrite, respectively. Emphasis of the microstructure and property characterisation was laid on through-thickness gradients of grain size, hardness, texture, impact toughness and tensile properties. Accordingly, the materials were characterised at different positions in the thickness. Grain size and texture were determined by means of Electron Backscatter Diffraction (EBSD). Sub-size Charpy as well as sub-thickness tensile test specimens were taken at different positions in the cross section. The results show that the link between microstructure and properties is not at all obvious. The influence of mean grain size, grain size distribution and texture is discussed in detail.

IPC2010-31251

EBSD STUDY ON TRANSVERSE TENSILE X80 GRADE PIPELINE STEEL

X80管线钢横向拉伸变形研究

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ABSTRACT

Transverse tension testing was carried out on an X80 grade linepipe to investigate the deformation behavior and the evolution of microstructure by means of SEM-EBSD (Electron Backscattered Diffraction) technique. Test results show that uniform elongation could achieve up to 7% in transverse tension for an X80 linepipe. Microstructural analysis shows that primary equiaxed ferrite grains obviously changed after the tension test to elongate along the length of pipeline body, but the substructure did not increase much revealing that the ferrite in X80 steel could contribute to a certain extent for ductile deformation. Orientation imaging of EBSD analysis displays that the texture components, such as γ-texture, and a little Goss and Copper texture, occurred after deformation. Otherwise, a small amount of primary α-texture still remains. It can be recognized that X80 has good deformational stability.

IPC2010-31252

MANUFACTURING OF 25MM HEAVY-WALL LINEPIPE USING THE HIGH FREQUENCY INDUCTION (HFI) WELDING TECHNIQUE, A CHALLENGE FOR A PIPE MANUFACTURER

采用高频感应焊接技术制造壁厚25mm管线管：制管企业的挑战

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ABSTRACT

The current thickness limit of the HFI technique is about 20,6mm for grades up to X80. It is mainly governed by the necessary forming load, the coil edge formability and above all the optimisation of the power/heat input requirements on the weld seam area. The availability of hot rolled coils in thicknesses up to 25mm has made possible the exploitation of the HFI limits to such thicknesses.Following the successful industrial HFI welding production of 609,6mm (24") x 25mm thick wall pipes at the CPWThisvi mill, the current paper deals with the development of the process regarding forming, welding, process automation and NDE inspection techniques for thicknesses up to 25mm. The latter made possible the broadening of the HFI process limits,

currently for grades up to X60. Details of the technology used are described along with the investigation of the influence of welding and post-weld heat treatment (PWHT) cycles on the microstructure of the welding zone (WZ) and heat affected zone (HAZ) of the hot-strip micro-alloyed high strength low alloyed (HSLA) steel chosen. Mechanical testing of the pipe body and weld seam was used to characterise their performance. The dimensional tolerances of the pipe products are also described.

Results of the study showed properties which were uniform and satisfied API 5L requirements. The above research demonstrates that the HFI technique has a clear potential to provide the energy market with lower cost-options for the construction of heavy wall pipes.

Keywords: HFI pipe production, micro-alloyed steel,thick gauge pipes, high grade pipes.

IPC2010-31257

INFLUENCE OF RESIDUAL STRESS ON THE HIC RESISTANCE OF HIGH FREQUENCY INDUCTION WELDED PIPES WITH REGARD TO PROCESS-SPECIFIC INFLUENCING FACTORS

针对工艺影响因素的高频感应焊管残余应力对氢致开裂抗力的影响

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ABSTRACT

Over the last decades an increase in the exploration and exploitation of impure oil and gas resources in remote environments under aggravated conditions has become necessary. This led to a growing demand for pipes with resistance to sour service conditions. Salzgitter Mannesmann Line Pipe has enhanced its product range of High-Frequency-Induction (HFI) welded pipes in recent years accordingly.

In the process of HFI welding of pipes, forming roles bend steel coil into a pipe which is then welded together without any filler metal. This cold forming results in residual stress, depending on the diameter and wall thickness of the pipe. The current state of technology is based on the perception that this residual stress has an adverse effect on the resistance of line pipes to HIC, because it amplifies – or if it is sufficiently high – even triggers the onset of HIC. Aim of this paper is to study the influence of residual stress on the resistance in HFI welded pipes to HIC with regard to process-specific influencing factors.

Four material strengths are selected for the tests.The first three material strengths (API 5L Grade from Grade B up to X65) are intentionally produced from non sour service material in order to obtain sufficient HIC damage. The highest material strength examined is a sour service material alternative to

ascertain whether under optimal material conditions HIC indications can result solely from high residual stress. Plate and pipe segments are examined by means of the crosssectioning method for longitudinal and circumferential residual stress at the process steps that influence the residual stress. A series of experiments under simulated residual stress to determine the HIC resistance of these pipe materials in NACE TM0284 test solution A is carried out using the four-point-bend test according to ASTM G 39, usually applied in sulphide stress cracking tests of line pipe steels. A characteristic HIC value, the crack area ratio CAR, is determined as a function of C and Mn content and residual stresses. To verify the results, FEM was used to model a test bar with the same geometry and to re-calculate the above-mentioned case.

The results of these experiments combined with the supporting theoretical considerations and modeling prove that in the case of HFI welded line pipes, the residual stress induced by the process has no negative impact on the resistance of HFI welded pipes to HIC.

IPC2010-31263

IMPROVED PIPELINE AUT INSPECTIONS USING LATERALLYFOCUSED ARRAYS

采用横向聚焦阵列改进管线的自动超声波检测

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ABSTRACT

Automated ultrasonic inspection of pipeline girth welds during construction relies on well-focused probes. With the arrival of industrial phased arrays, focusing in the vertical direction became straightforward. However, arrays are generally unfocused in the horizontal (circumferential) direction. This can lead to oversizing of small defects, and unnecessary repairs. Modeling was performed to determine the optimum and most cost-effective method of focusing laterally. These results showed that mechanically curving the array in the passive axis provided excellent results. Suitable arrays were manufactured and tested on calibration notches and weld defects. Comparative results will be shown between unfocused and focused arrays. These focused arrays are now a common product on PipeWIZARD.

IPC2010-31273

THE EFFECT OF SAMPLE FLATTENING ON YIELD STRENGTH MEASUREMENT IN LINE PIPE

试样压平对测得管线管的屈服强度的影响

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ABSTRACT

Tensile testing is a key part of the qualification process of Line Pipe. When qualifying pipe products various items are considered when tensile testing; Yield Strength (YS), Ultimate Tensile Strength (UTS), Percent Elongation (%EL), and the Yield Strength to Tensile Strength Ratio (Y/T) are all important. Of these, the YS is the most critical and yet the most sensitive to both preparation and measurement techniques. During the pipe forming process, the base material is plastically formed into a curved shape, and then welded into the final product. The Transverse to Pipe Axis (TPA) tensile specimen removed for testing is curved and must be flattened prior to testing. The flattening process is varied in many facilities and the standards to which testing is conducted are not specific enough to ensure uniformity of procedures. ASTM acknowledges flattening processes and the degree of flatness “may affect test results”,though no guidance is given.

This paper will provide an overview of ongoing research efforts, concerning the measurement of the Yield Strength of TPA tensile specimens and its relationship to curvature and flattening methods, prior to testing. By comparing flattened strap tests, to round bar and ring expansion tests, it is shown that the flattened strap test provides a conservative estimate of the actual YS of the pipe.

IPC2010-31277

SKELP END WELDING IN HELICAL PIPE PRODUCTION

螺旋钢管生产中的卷板对头焊接

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ABSTRACT

The production of large diameter pipe by the helical welding process requires that consecutive coils be welded together to facilitate the advance of each subsequent coil through the forming section of the pipe mill. Traditionally, the skelp ends have been joined by a single-pass submerged arc weld simply designed to join the skelp ends together and provide sufficient strength and ductility to survive the pipe forming operation. Subsequent to pipe forming, the

length of pipe containing the skelp end weld (SEW) has been cut off and discarded. This process results in both a substantial yield loss as well as additional processing costs as the shortened pipes are later double jointed to produce full size lengths. To overcome these inefficiencies, a process has been developed for making high quality skelp end welds which meet API and CSA requirements. In this paper, the welding process will be described and evaluation of the integrity of the skelp end weld is discussed. Of particular interest are the properties of both the weld and associated heat affected zone in the vicinity of the “T” where the skelp end weld merges with the helical weld. This paper demonstrates that skelp end welds meeting rigorous integrity specifications can be successfully produced.Incorporation of suitable skelp end welding and inspection procedures in the pipe production process significantly enhances the efficiency of helical pipe production.

IPC2010-31280

FIELD GIRTH WELD HAZ TOUGHNESS IMPROVEMENT – X80/GRADE 550

X80/550钢级野外作业环焊缝热影响区韧性的提高

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ABSTRACT

Field welding and field weld rework can be a significant cost in the construction of pipelines. Heat affected zone (HAZ) material adjacent to a weld is of particular concern because the base material microstructure has been altered significantly. In instances where Engineering Critical Assessment (ECA) is used for defect acceptance, optimizing and/or improving the base material for field weldability will reduce repair welding rates,which in turn improves project economics.

Several alloys of X80/Grade 550 were assessed. All materials were robotically welded to simulate a typical mechanized field weld. Two of the alloys were also welded using a field mechanized welding system. These welds were subjected to tests assessing field weldability. Weldability is a broad term used to summarize various material properties related to the level of conduciveness to welding. For the purposes of this paper, the term field weldability is used to describe the level of HAZ toughness of a material subjected to field welding conditions. Charpy V-notch (CVN) and crack tip opening displacement (CTOD) tests were utilized to assess the toughness of the welded material. Optical microscopy was employed to characterize the HAZ microstructures. In addition,all materials were subjected to HAZ thermal processing in a Gleeble thermo-mechanical simulator. Gleeble dilatometry

curves were constructed to characterize phase transformation behavior, and tested materials were used to characterize HAZ microstructures using optical microscopy. Gleeble HAZ CVN specimens were processed in order to assess the toughness of a uniform, idealized HAZ microstructure.

It was found that HAZ toughness was better for material chemistries that promote lower phase transformation temperatures. Lower phase transformation temperatures caused the formation of favorable microstructural phases, with finer coarse grain HAZ (CGHAZ) prior austenite grain size, as well as fine packet size. Phase transformation temperature and prior austenite grain size were found to be most dependant on the carbon and carbon equivalent content of the material. The steel containing the lowest amount of carbon displayed the highest phase transformation temperature, coarsest CGHAZ prior austenite grain size, and lowest HAZ toughness, as measured by CTOD and CVN tests.

IPC2010-31293

TECHNICAL CHALLENGES OF HEAVY WALL HFW PIPE PRODUCTION FOR BORD GÁIS ÉIREANN PIPELINE PROJECT

Bord Gáis Éireann管线项目用厚壁HFW钢管生产的技术挑战

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ABSTRACT

The recently constructed Bord Gáis Éireann, Curraleigh West to Midleton pipeline runs due north from the Midleton compressor station near the city of Cork in Southern Ireland.The 47.5 km, 610mm outside diameter pipeline, comprises over 30 km of 9.5 mm and 17 km of 19.1 mm wall thickness L450MB (X65) grade pipe. The pipe for the project was produced by Corinth Pipeworks (CPW), at its state of the art HFW pipe mill at Thisvi, Greece and represents a first in terms of the quantity of 19.1 mm L450MB (X65) HFW pipe produced by the mill for a specific project.

The paper outlines the engineering approach adopted for the pipeline before describing in detail the production challenges faced by the pipe mill in successfully completing this demanding pipe order. Production of the 9.5 mm wall thickness pipe was not anticipated to present any particular difficulties. However, the principal concern associated with the manufacture of the 19.1 mm pipe was that the combination of wall thickness and strength level was toward the upper end of the commercially supplied wall thickness-strength combinations for HFW produced linepipe, particularly as the actual strength of the starting coil was well above the minimum specified level for L450MB (X65).

In addition, to accommodate the demanding drop weight tear test (DWTT) toughness requirement the chemical composition of the 19.1 mm coil strip was above the permitted limits of the parent pipe standard EN 10208-2 [1] for the elements Cu & Ni, and the yield to tensile ratio was also above the 0.87 maximum level required by EN 10208-2 for L450MB (X65) grade pipe. Potential risks were therefore identified prior to production and mitigated by several methods detailed in the paper, including for example; increased initial production test frequency, close monitoring during pipe production, duplicate testing to verify mill results, identification of potential construction issues and weldability testing.

A summary of production experience including statistical data for the production of both 9.5 mm and 19.1 mm pipe is presented. Also covered are the results of a supplementary investigation which makes a further assessment of the influence of the welding and heat treatment cycles on the final pipe properties. The paper concludes by referring to the overall successful construction phase of the project.

IPC2010-31297

CHALLENGES IN JOINING THERMOSET COMPOSITE PIPING

热固合成管连接技术中的挑战

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ABSTRACT

The aim of this paper is to examine solutions and challenges related to joining thermoset composite piping. Fiber reinforced polymers (FRP) have been used in piping systems for more than 40 years. Higher specific mechanical properties and corrosion resistance of FRP make them a potential candidate for replacing metallic piping structures. Despite the advantages associated with FRP, their application is still limited due to, in part, unsatisfactory methods for joining composite subcomponents and inadequate knowledge of failure mechanism under different loading conditions. Adhesively bonded joints are attractive for many applications since they offer integrated sealing, minimal part count and do not require pipe extremities with complex geometries such as threads or bell and spigot configurations. So far, the majority of work reported in the technical literature on adhesively bonded pipe joints is concerned with lap joints employing wrapping techniques to produce overlap sleeve connections. More recently, a joining technique was proposed that replaces the wrapping technique with filament-wound overlap sleeve couplers that are adhesively bonded to the pipe extremities. In the present article, various joining techniques for FRP piping through adhesive bonding are discussed, and damage mechanisms under different loading conditions

are examined.

Keywords: Fiber-reinforced polymer piping; composite piping;joining;adhesive bonding.

IPC2010-31299

GUIDELINES FOR PRODUCTION OF API PIPELINES STEELS SUITABLE FOR HYDROGEN INDUCED CRACKING (HIC) SERVICE APPLICATIONS

适于氢致开裂服役条件用 API 管线钢的生产指南

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ABSTRACT

Worldwide oil and natural gas reserves can be classified as either sweet or sour service. The sour service classified oil and natural gas reserves contain some level of H2S making the product flowing through a steel pipeline corrosive. Due to this, the majority of the oil and natural gas reserves that have been drilled are of the sweet service nature. However as demand continues and supplies change, many of the remaining oil and natural gas reserves contain the H2S component and are of a sour service nature. These oil and natural gas reserves containing the H2S component through a corrosion mechanism will allow for diatomic hydrogen – in the presence of moisture – to disseminate to monatomic hydrogen and diffuse into the pipeline steel microstructure. Depending on the microstructure and level of cleanliness the monatomic hydrogen can become trapped at areas of high residual stress, recollect to diatomic hydrogen and creating partial pressures that exceed the tensile strength of the steel resulting in cracking. Therefore transmission pipelines are being built to transport sour service oil or natural gas requires steels with hydrogen induced cracking (HIC) resistance.

Alloy designs, steel making processing, continuous casting, plate or strip rolling, pipe forming, and last not least corrosion testing are all key components in producing pipeline steels that are resistant to HIC applications and meeting the NACE TM0284 specifications. However, producing steels that have good HIC performance do not necessarily meet other mechanical property requirements such as strength and YT ratios. Balance has to be achieved to meet not only the HIC requirements but the other required mechanical properties.

Mastering this complex HIC process poses a serious challenge to pipe producers and their primary material suppliers. The capability of producing HIC steel grades according to critical specifications and/or standards clearly distinguishes excellent steel producers from good steel makers. This paper will discuss the basics of the hydrogen induced cracking phenomenon, the

requirements of the NACE TM0284 specification and give guidelines for steel production of API pipeline steels that not only can meet the specification requirements the NACE testing but also fulfill the other mechanical property requirements.

IPC2010-31301

MICROSTRUCTURE AND MECHANICAL PROPERTY PERFORMANCE OF COMMERCIAL GRADE API PIPELINE STEELS IN HIGH PRESSURE GASEOUS HYDROGEN

在高压氢气中商业用API管线钢的微观结构和力学性能

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ABSTRACT

The continued growth of the world's developing countries has placed an ever increasing demand on traditional fossil fuels. This increased demand for fossil fuels has lead to increasing research and development of alternative energy sources. Hydrogen gas is one of the potential alternatives under development. It is anticipated that the least expensive method of transporting large quantities of hydrogen gas is through steel pipelines. It is well known that

hydrogen embrittlement has the potential to degrade steel's mechanical properties. Consequently, the current pipeline infrastructure used in hydrogen transport is typically operated in a conservative fashion, in particular lower operating pressures, lower strength steels, and heavier pipe wall thicknesses. This operational practice is not conducive to economical movement of significant volumes of hydrogen gas as an alternative to fossil fuels.

The degradation of the mechanical properties of steels in hydrogen service depends on the microstructure of the steel. An understanding of the relationship of mechanical property degradation of a given microstructure on exposure to hydrogen gas under pressure can be used to evaluate the suitability of the existing pipeline infrastructure for hydrogen service and guide alloy and microstructure design for new hydrogen pipeline infrastructure. To this end, the microstructures of relevant steels and their mechanical properties in relevant gaseous hydrogen environments must be fully characterized to establish suitability for transporting hydrogen.

A project to evaluate four commercially available pipeline steels alloy/microstructure performance in the presences of gaseous hydrogen has been funded by the US Department of Energy along with the private sector. The microstructures of four pipeline steels were characterized and tensile testing was conducted in gaseous hydrogen and helium at pressures of 5.5 MPa (800 psi), 11 MPa (1600 psi) and 20.7 MPa (3000 psi). Based on reduction of area, two of the four steels that performed the best across the pressure range were selected for evaluation of fracture and fatigue performance in gaseous hydrogen at 5.5 MPa (800 psi) and 20.7 MPa (3000 psi).

This paper describes the work performed on four commercially available pipeline steels in the presence of gaseous hydrogen at pressures relevant for transport of hydrogen in pipelines. Microstructures and mechanical property performances are compared. In addition, recommendations for future work related to gaining a better understanding of steel pipeline performance in hydrogen service are discussed.

IPC2010-31310

EFFECT OF FRACTURE SPEED ON DUCTILE FRACTURE RESISTANCE – PART 1: EXPERIMENTAL

断裂速率对延性断裂抗力的影响：第一部分-试验

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ABSTRACT

The effect of fracture speed on the ductile fracture resistance of line-pipe steels can have an important effect in the basic understanding of the

toughness requirements for crack arrest. Over the last few decades, it has become recognized that the drop-weight tear test (DWTT) better represents the ductile fracture resistance than the Charpy test since it utilizes a specimen that has the full thickness of the pipe and has a fracture path long enough to reach steady-state fracture resistance. However, the fracture speed in the DWTT is typically 50 to 60 feet per second (15.2 to 18.3 m/s), whereas the fracture speed in the full-scale pipe test is 300 to 1,000 fps (91.4 to 305 m/s).

Recently, the authors have extended the DWTT work and developed a modified back-slot DWTT specimen to obtain higher fracture speeds. One aspect of this modified specimen was to increase the width of DWTT sample from the standard 3-inch (76.2 mm) to 5-inch (127 mm). This was done to increase the ligament length in a relatively deep back-slotted specimen to capture more steady-state data. The initial experimental results demonstrated that this type of specimen can be used to obtain higher fracture speeds. Furthermore, the experimental results clearly showed the effect of fracture speed on the ductile fracture resistance.

In this paper, to extend the work on modified back-slot DWTT specimens, the tup was instrumented to measure the load during dynamic impact. From this, the load-displacement curve, steady-state energy (or energy per area) was obtained for the modified back-slot DWTT specimens. These results were compared to those obtained from the standard 3-inch specimens. These results also clearly showed the effect of fracture speed on fracture resistance.

IPC2010-31334

A NEW APPROACH TO ESSENTIAL WELDING VARIABLES IN GIRTH WELDING OF HIGH STRENGTH PIPE STEELS

高强度管线钢的环焊缝焊接时确定重要焊接变量的新方法

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ABSTRACT

In the narrow groove joints typically used for mechanized GMA W girth welding of high strength pipe,weldment properties are controlled by a large number of variables. The groove geometry, the bevel offset distance,the pass sequence and nurn ber of passes, the heat input per pass, the preheat and interpass temperatures, single vs. dual torch configuration, and the chemical composition of the consumable and the base pipe can all have an effect on the weldment properties. Determining the primary and secondary variables that control mechanical properties is a daunting task. Use of an integrated thermal-microstructural model has allowed virtual experiments to be

conducted by varying the aforementioned welding variables to identify the primary and secondary drivers that control thermal behavior, microstructural evolution and ultimately weld and HAZ mechanical behavior Outputs from this model have been used to correlate the essential process variables with weld hardness.

IPC2010-31362

CRYSTALLOGRAPHIC TEXTURE CONTROL HELPS IMPROVE PIPELINE STEEL RESISTANCE TO HYDROGEN-INDUCED CRACKING

晶体学结构控制有助于提高管线钢氢致开裂抗力

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ABSTRACT

Low-carbon steel specimens, all within API (American Petroleum Institute) specifications, were produced following different thermomechanical paths. After austenization, the samples were rolled and recrystallized. The rolling process was carried out using different reduction-in-thickness degrees and finishing temperatures. The investigated steels showed similar microstructural features but differed considerably in their crystallographic textures and grain boundary distributions. After cathodic hydrogen charging, hydrogen-induced cracking (HIC) was detected in the hot-rolled recrystallized steels, whereas the cold and warm-rolled recrystallized steels proved resistant to this damage. Among the investigated specimens, the HIC-stricken show either the strongest {001}ND texture fiber, the smallest fraction of low-angle grain boundaries, or the weakest {111}ND (γ) texture fiber ({hkl}ND representing crystallographic orientations with {hkl} planes parallel to the steel rolling plane). In contrast, the HIC-resistant steels show the weakest {001}ND texture fiber, the largest fraction of low-angle grain boundaries, and the strongest γ fiber. These results support the hypothesis of this and previous works, that crystallographic texture control, through warm rolling schedules, helps improve pipeline steel resistance to hydrogen-induced cracking.

IPC2010-31363

HYDROGEN-INDUCED CRACK INTERACTION AND COALESCENCE: THE ROLE OF LOCAL CRYSTALLOGRAPHIC TEXTURE

氢致裂纹的交互和合并：局部晶体学结构的作用

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ABSTRACT

The role of local crystallographic texture (microtexture) in hydrogen-induced crack interaction and coalescence is investigated in pipeline

steels using stress simulation and orientation imaging microscopy. It is shown that, depending on the material's microtexture, crack interaction and coalescence can significantly depart from the conditions predicted by the mixed-mode fracture mechanics of isotropic linear elastic materials. The results of stress simulations and microtexture analyses conducted on several observed crack interaction zones show that the presence of cleavage planes and slip systems favorably oriented to the mixed-mode stresses can activate low-resistance transgranular paths along which cracks can merge. In such situations, the response of the material to the mixed-mode stress state resulting from crack interaction produces results drastically different to that predicted by the fracture mechanics of isotropic linear elastic materials. This evidences the need for considering the material's crystallographic texture when developing predictive models for the stepwise propagation of hydrogen-induced cracking in pipeline steels.

IPC2010-31371

EFFECT OF STRAIN AGEING ON YIELD STRENGTH AND POST YIELD BEHAVIOR OF FCAW-G FERRITIC WELD METAL

应变时效对 CO2 药芯焊丝气体保护焊焊缝金属的屈服强度以及后效屈服行为的影响

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ABSTRACT

Ferritic weld metal was deposited with gas shielded flux cored arc welding (FCAW-G) process. The nitrogen level in the deposited weld metal varies typically between 20 to100 ppm. Nitrogen is a fast diffusing solute element that is known to cause strain ageing affecting both strength and toughness. Weld metal was produced with intentional additions of two strong nitride formers, titanium and vanadium. All-weld metal tensile samples were subjected to varying levels of strain, aged at 170ºC for 20 minutes and reloaded to failure. Both the yield and tensile strength increased with increase in pre-strain confirming the presence of strain ageing. The strain hardening rate is also seen to change with strain ageing. There is also a corresponding decrease in the uniform elongation with increase in nitrogen and prestrain.The effect of strain ageing treatment on weld metal toughness was also evaluated. A nominal 2%-3% strain was imposed on the weld metal by straining it in the direction of welding and Charpy V-Notch toughness of the weld was measured. The ductile to brittle transition temperature (DBTT) of the weld metal was estimated by measuring the percent shear and the weld metal toughness at

different temperatures.The DBTT of the weld metal is seen to shift slightly to highe temperatures with increase in pre-strain. However there was a dramatic drop in the upper shelf energy and a consistent decrease in the average toughness of the weld metal at all temperatures. The as-welded and reheat microstructure of the weld metal was characterized using optical and electron microscopy techniques. The possible implications of strain ageing on pipeline girth weld procedure qualification and inservice integrity are discussed.

IPC2010-31372

INVESTIGATIONS INTO THE MICROSTRUCTURE – TOUGHNESS RELATION IN HIGH FREQUENCY INDUCTION WELDED PIPES

高频感应焊管微观结构和韧性之间联系的研究

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ABSTRACT

In the present paper, investigations performed on ArcelorMittal X65 linepipe steel in order to understand the effects of high frequency induction (HFI) welding process and in-line postweld heat treatment on weld properties are described. The factors that potentially can affect weld toughness, such as microstructure, grain size, precipitates, hardness, inclusions, and texture, are evaluated and discussed systematically in order to correlate weld microstructure with toughness of the HFI welded pipes.

IPC2010-31373

THERMAL SIMULATION AND ITS EXPERIMENTAL VERIFICATIONS FOR GIRTH WELDS IN HIGH-STRENGTH PIPELINES

高强度管线环缝的热模拟和试验验证

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ABSTRACT

Girth welds in high-strength pipeline constructions are often made with mechanized pulsed gas-metal-arc welding (PGMAW) process. Welding of the high strength steels poses a number of challenges because of the sensitivity of weld mechanical properties to variations in welding parameters and material properties. In addition to the unique characteristics of narrow groove weld geometry and multiple weld passes, the fabrication of P-GMAW girth welds sometimes also employs alternative welding processes such as dual torch or tandem wire in order to increase pipeline construction productivity. In order to understand the dependency of weld properties on welding processes and their parameters, a transient thermal model for multi-pass girth weld had been proposed and successfully developed. The heat transfer model used the superposition principle of heat sources to handle the welding processes with multiple wires or multiple passes. This paper presents the latest development of this numerical approach and its verification against experimental measurements of thermal cycles from X100 girth welds under different welding conditions. A number of X100 pipe girth welds under different welding conditions were made for the verification purpose. The welding conditions include single torch and dual torch P-GMAW process, 1G and 5G welding. Thermocouples were placed in the heat-affected zone (HAZ) and the weld-pool for the measurements of thermal cycles. The measured thermal cycles and cooling times from 800oC to 500oC were compared to those predicted by the thermal model. Very good agreements between the measured results and the numerical prediction by the thermal model were achieved.

IPC2010-31374

SIMULATION OF MICROSTRUCTURE EVOLUTION AND ITS EXPERIMENTAL VERIFICATIONS FOR GIRTH WELDS IN HIGH-STRENGTH PIPELINES

高强度管线环缝微观组织的演化模拟和试验验证

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ABSTRACT

Girth Welding of high strength steels such as X80 or X100 poses a number of challenges because of the sensitivity of weld mechanical properties to variations in welding parameters and material properties. This dependency is further complicated by the application of alternative welding processes with multiple wires, tandem wire or dual torch welding, for example. In order to correlate the relation between weld mechanical properties and the welding conditions, an integrated thermal and microstructure model has been developed. Given the welding conditions, the thermal model is able to simulate the local thermal cycles for a girth weld with multiple passes and multiple electrode wires. In the mean time, a microstructure model, using the thermal cycles obtained from the thermal model as input, simulates the microstructure evolution both in the weld metal and the HAZ as the welding progresses. This paper presents the latest development of this microstructure model and its verification against metallurgical measurement data from X100 girth welds. These welds included girth welds made under practical welding conditions and experimental welds made with X100 plates. The measured hardness was compared to the predicted by the microstructure model. The comparison indicated that the microstructure was able to predict the hardness profiles in a multi-pass girth weld and the general trend of variation as a function of welding conditions. In order to improve the accuracy of hardness prediction, the areas of improvement in the microstructure model have been identified.

KEYWORDS: pipeline, girth weld, P-GMAW, hardness microstructure.

IPC2010-31402

WELD METAL TOUGHNESS – SOURCES OF VARIATION

焊缝金属韧性：差异的根源

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ABSTRACT

Many material properties are statistical in nature. If one measures the same property of the same material repeatedly,ideally the result is a normally distributed “bell” curve about a mean value. This ideal case does not necessarily hold true for all mechanical properties of interest in steel weld metals.Tensile strength measurements tend to exhibit normal behavior for a given weld metal chemical composition deposited using a reasonable consistent welding procedure, Figure 1a. However,toughness measurements are not nearly as well-behaved or predictable. In a tensile test, assuming a

defect free weld, the strength measurement is based on the bulk response of the material throughout the gage length. In a Charpy V-notch (CVN) impact test, again assuming a defect free weld, the toughness measurements are controlled largely by the very local response of the material at the point of highest stress where fracture initiates just below the notch.

This paper presents a detailed assessment of a C-Mn weld metal and explains how CVN toughness can vary from less than 20 ft-lbf to over 200 ft-lbf in the same weld, often with test specimens located adjacent to one another in the test weld,Figure 1b. The much localized microstructure features that give rise to this degree of variation are a combined result of chemical composition, welding procedure, pass sequence, and individual welder technique. The evidence suggests that retained austenite in coarse grained regions of the as-deposited weld metal transform to martensite at the CVN test temperature, effectively creating local brittle zones in the weld metal. This example provides basis for examination of a broader range of microstructural discontinuities in steel weld metals and their potential influence on toughness measurement.

IPC2010-31406

CHARACTERIZATION OF WELD METAL DEPOSITED WITH A SELF SHIELDED FLUX CORED ELECTRODE FOR PIPELINE GIRTH WELDS AND OFFSHORE STRUCTURES

焊接管线环缝和海洋结构用自保护药芯焊丝生成的焊缝金属的特征

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ABSTRACT

Pipeline girth welds deposited with a self-shielded flux cored electrode process (FCAW-S) have been characterized to assess the effect of micro-alloying elements on microstructure and precipitate evolution and correlate it to strength and toughness. A 2.0 mm diameter electrode was used to deposit weld metal in a 12.7 mm thick API grade X-70 pipe joint. The weld metal properties were characterized and shown to overmatch the pipe. The DBTT of the weld metal has been determined through Charpy V-Notch toughness measurements.The effect of heat input and welding procedure has been assessed over a range of heat inputs (1-1.5 kJ/mm.). The effect of dilution from the base plate on toughness has been assessed by measuring the sensitivity of weld metal toughness to changes in carbon content. The as-welded region of the weld has been characterized using different

characterization techniques.Ferritic weld metal deposited with a self-shielded arc welding process has intentional additions of aluminum, magnesium, titanium and zirconium. This results in a complex precipitation process that has been characterized with a combination of electron microscopy techniques. The effect of micro-alloying additions on the variant selection during the austenite to ferrite transformation and microstructure evolution has been studied with electron back scattered diffraction (EBSD) in conjunction with orientation imaging microscopy (OIM). Transmission electron microscopy (TEM) was used to characterize the precipitate evolution in these welds. The evidence shows that the formation of a spinel oxide is critical for the nucleation of nitrides of zirconium and titanium and prevents the agglomeration of aluminum rich oxides and the formation of large aluminum nitrides. The evolution of precipitate formation is critical to limit large inclusions and improve weld metal toughness. The presence of titanium and zirconium increases the fraction of high angle grain boundaries within the microstructure resulting in increased resistance to crack propagation. The characterization of the microstructures at two different carbon contents indicates the greater propensity to form twin related variants with increase in carbon content. This suggests a lower transformation temperature of austenite and may be the reason for poor toughness.

IPC2010-31411

MECHANICAL PROPERTIES AND MICROSTRUCTURE OF WELD METAL AND HAZ REGIONS IN X100 SINGLE AND DUAL TORCH GIRTH WELDS

X100单和双焊枪环焊缝焊缝金属和热区的力学性能和微观组织

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ABSTRACT

The main objectives of the current study were to further develop tensile and toughness testing protocols and to provide a better understanding of the factors that control both weld metal and HAZ microstructure and properties in pipeline girth welds. In this investigation, two series of rolled (1G) girth welds were made in X100 pipe of 36 in. diameter and 0.750 in. wall thickness using two pulsed-gas metal arc welding process variants: single and dual torch. The small-scale testing program included evaluations of all-weld-metal tensile strength, Charpy impact and standard fracture toughness measured by single-edge bend SE(B) tests, along with preliminary fracture toughness results using a single-edge tension SE(T) test developed at CANMET. Additional information was obtained from detailed microstructural

characterizations of weld metal and HAZ regions along with microhardness testing.

All-weld-metal tensile tests using round and strip tensile specimens showed variations with through-thickness location and in some case with clock position. Full stress-strain curves were generated, and 0.2% offset yield strength, flow stress,ultimate tensile strength, and uniform strain were measured and compared with pipe properties using calculated weld strength mismatch factors based on these properties.

Charpy V-notch transition curves were generated for both weld metal and HAZ (notched within 0.5 mm of the fusion line). Fracture toughness of both weld metal and HAZ regions of single torch welds was assessed using standard SE(B) testing procedures with Bx2B preferred specimens notched through–thickness at the weld centerline and in the HAZ (within 0.5 mm of the fusion line). Full J-resistance curves were measured using SE(T) tests of surface-notched WM and HAZ specimens; the SE(T) test was designed to match the constraint of full-size pipeline girth welds.

IPC2010-31421

X100 WELDING TECHNOLOGY – PAST, PRESENT AND FUTURE

X100焊接技术：过去，现在和未来

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ABSTRACT

A significant amount of research has been conducted within the last decade on the development of X100 line pipe and associated welding technology; including, several field demonstration projects of limited size and scope. Although considerable advances in steelmaking and pipeline construction have occurred, innovations in welding process technology generally lag pipeline industry needs. Clearly, the number of historically viable welding options declines as pipe strength increases. Weld strength becomes more sensitive to cooling rate variation, cold cracking sensitivity increases, and overall weldability tends to decline. Also, achieving the balance between weld strength, toughness, and ductility necessary for pipeline performance requires more highly controlled welding practice, procedures, precision in weld bevel design, and pass sequence. Successful fabrication and field pipelay welding requires greater control of essential welding variables in order to satisfy increasingly stringent weld property requirements.

Accordingly, there are few proven welding process options for X100 and detailed knowledge resides within a small number of oil/gas and contractor companies. Recognizing that industry wide implementation of X100 requires the range of manual, semi-automatic and automatic (mechanized) welding processes needed for double jointing, mainline, tie-in and repair, US Department of Transportation Pipeline and Hazardous Materials Safety

Administration (DOT-PHMSA) and Pipeline Research Council International (PRCI) have cofounded a consolidated program to begin addressing the issues (Project PR-354-074506). This paper summarizes the program findings that address the current state of the art regarding welding technology applied to X100 pipeline construction. The main issues addressed are:

synopsis of experience,

current status and pending developments in welding processes and consumables,

assessment of first and second level contractor capability,and

key knowledge and experience gaps.

IPC2010-31422

EXPERIMENTAL INVESTIGATION OF SPIRAL SEAM INDUCTION BENDS

螺旋缝感应弯管的试验研究

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ABSTRACT

The three kinds of dimensions that is Φ325mm×8mm,Φ426mm×8mm and Φ711mm×10.3mm X52 spiral seam induction bends were manufactured via the induction bending process. Based on that, the property and structure of spiral seam induction bends were investigated. According to the processing technic and design feature of spiral seam bend, the destructive test sampling plan of spiral seam induction bend was proposed. Through the mechanical property tests and design proof test, the spiral seam induction bend was studied and evaluated. The tension and impact tests results show that the strength-toughness of spiral seam induction bend can approach the property of mother pipe when the suitable process was adopted. The transverse guided-weld bend tests results show that the root bend samples in several fixed location of Φ325mm×8mm bend pipes crack, which indicate that the smaller diameter spiral seam pipe is not fit for the hot bending.The observational check results show that the welding joint misalignment occurs at the inner arc of Φ711mm×10.3mm spiral seam induction bend, which indicate that the configuration of spiral seam induction bend is easy to be affected during bending process with the decrease of thicknessto-radius ration of pipe. The design proof test of Φ426mm×8mm bend pipe shows that the spiral seam induction bend does not rupture at the computed proof test pressure.

IPC2010-31461

APPLICABILITY OF EXISTING FRACTURE INITIATION MODELS TO HIGH-STRENGTH STEEL LINE PIPE

现有起裂模型对高强钢管线管的适用性

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ABSTRACT

The original fracture criteria developed by Maxey/Kiefner for axial through-wall and surface-cracked pipes have worked well for many industries for a large variety of low strength and low toughness materials. However, newer line-pipe steels have some unusual characteristics that differ from these older materials. One example is a single test that has demonstrated that X100 line-pipe with an axial through-wall-crack can fail at pressures about 30 percent lower than predicted with commonly used analysis methods for older steels. Thus, it is essential to review the currently available models and investigate the applicability of these models to newer highstrength line pipe materials.

In this paper, the available models for predicting the failure behavior of axial-cracked pipes (through-wall-cracked and external surface-cracked pipes) were reviewed. The applicability of these models to high-strength steel pipes was investigated by analyzing limited full-scale pipe fracture initiation test results and the shortcomings were identified. For both through-wall and surface cracks, the major shortcomings were related to the characterization of the material toughness,which generally leads to non-conservative predictions in the *JT* analyses. The findings in this paper may be limited to the test data that was consider for this study. The requisite characteristics of a potential model were also identified.

IPC2010-31467

PRESSURE AND BENDING TESTS ON FIBREGLASS AUGMENTED STEEL TECHNOLOGY PIPES

玻璃纤维加强钢钢管的压力和弯曲测试

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ABSTRACT

The demand for the transportation of natural gas over long distances requires larger diameter pipes operating at higher pressure levels. A new technology, Fibre Augmented Steel Technology Pipe (FAST-Pipe™), emerges as one of the more cost-effective options to achieve this goal. As part of the

qualification program of this new technology, a total of 15 tests were conducted on FAST-Pipe™ specimens fabricated from12.75-inch outer diameter, 0.25-inch wall thickness, ERW,X60 steel liners hoop-wound with 0.2- and 0.35-inch thick dryfibreglass.

This paper presents the results of several tests, including burst pressure testing of eight specimens to assess the effects of external environment (frozen and frozen/thawed), load duration(0 to 1,200 hours) and the wrap thickness (0.20 to 0.35 inch) on the burst capacity of the FAST-Pipe™. Variations of these parameters resulted in burst capacities ranging from 5,550 to 7,360 psi as compared to the unwrapped pipes whose burst capacities were in the range of 3,400 to 3,650 psi. It was observed during the cold burst tests that failure did not occur at the frozen or frozen/thawed section; instead, failure occurred in the transition zone between the frozen or frozen/thawed section and the dry (unfrozen) region.

This paper also presents the results of two specimens that were subjected to constant internal pressure and imposed curvatures until buckle formation (pressure-bend tests) to assess the effects of wrap thickness (0.35- to 0.20-inch) on the bend capacity of the FAST-Pipe™ and to develop data from which to validate the analytical predictions. As expected, the overall curvature and moment capacities were higher for the 0.35-inch thick wrap than that for the 0.20-inch wrap.

IPC2010-31469

CONSTRUCTION OF THE X100 OPERATIONAL TRIAL PIPELINE AT SPADEADAM, CUMBRIA, UK

英国坎布里亚郡Spadeadam 的X100管线试验段的建设

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ABSTRACT

As part of an ongoing pipeline technology programme for BP Alaska, a 0.8 km, 48-inch diameter, X100 demonstration pipeline was constructed and operated for a period of two years. The pipeline was constructed using largely conventional techniques, with the exception of the mainline welding process, where a high productivity system was used. Mainline welding on X100 pipe was accomplished using a single tandem wire GMAW system offered by Serimax. Tie-in and fabrication welding was accomplished using vertical-down

STT root pass and a vertical-up mechanised FCAW system. This paper discusses key features of the welding specification, presents key weld qualification results, reflects on the field welding experience and makes some general remarks about the construction experience.

KEYWORDS
Pipeline; X100; High Strength Linepipe; Welding; Single Tandem GMAW; FCAW; STT.

IPC2010-31475

A NEW MODEL FOR DYNAMIC CRACK PROPAGATION AND ARREST IN GAS PIPELINES

输气管线动态裂纹扩展和止裂的一种新型模型

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ABSTRACT

A new model of unstable ductile crack propagation and arrest of pressurized gas pipeline is presented. The model couples pipe deformation and fracture with gas decompression. The model also takes account of backfill effect. Pipe deformation and pressure changes are obtained by solving one-dimensional differential equations. Validity of the model was checked by comparing with published full-scale burst test data. The model can predict history of crack velocity and arrest crack length with fairly good accuracy. The model can be applied to wide ranges of gases, pipe grades and pipe sizes because it does not rely on parameter adjustment by experimental data sets but is based on physical assumptions.

IPC2010-31477

Waveform Controlled Welding in ASME Section IX

ASME第四部分波形控制的焊接

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Abstract

Metallic pipe is produced to meet API, ISO or other industry specifications. When the manufacturing process involves welding of a longitudinal or spiral seam, the welding is typically done to the standards of ASME Section IX. Girth welding of pipe is often performed using ASME Section IX standards and pulsing waveforms.

In 2006, a task group was set up in ASME Section IX to explore waveform controlled welding and recommend code changes. The recommendations were submitted for approval, and the resulting code changes were published in the 2010 edition of ASME Section IX. The changes deal with the way energy or power is measured and the resulting calculation of heat input. This paper will explore differences in the measurement and calculation methods when using waveform controlled welding and discuss why these occur. The code changes will be presented. Detailed explanations will be given of how to comply with the new standards using either new or existing procedure qualifications.

IPC2010-31503

DRACORROSION BEHAVIOR OF HAZ BETWEEN C4 NiCKEL-BASE ALLOY / X60 STEEL DISSIMILAR METAL WELDMENTS

C4镍基合金／X60钢不同金属焊接热影响区的腐蚀行为

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ABSTRACT

C4 nickel-base alloy and X60 steel were fabricated by Tungsten Inert Gas Welding (TIG) process using a CrNiMo-3 nickel base alloy welding wire filler metal under 100A welding current. The microstructure of welding joint was analyzed by SEM. Corrosion behaviors of heat effect zone (HAZ) and X60 steel matrix were investigated by electrochemical measurement. The obtained results show that weld metal zone consists of fully dendrite structure and the austenite grain of C4 nickel-base alloy coarsening in over-heat HAZ. The HAZ of X60 steel includes coarse (GHAZ) and fine grained zones (FGHAZ). Phase change from bulk ferrite with a small amount of pearlite to granular bainite at CGHAZ. Corrosion current density of matrix of X60 steel is between FGHAZ and CGHAZ.

IPC2010-31520

RESEARCH PROGRESS ON FRICTION STIR WELDING OF PIPELINE STEELS

管线钢搅拌摩擦焊的研究进展

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ABSTRACT

Friction Stir Welding (FSW) has been widely commercialized to join aluminum alloys, but is yet to be broadly applied to structural steels. The primary difficulty in welding steels relates to severe loads and temperatures experienced at the interface between the FSW tool and the base material. These conditions are challenging even for the most advanced and expensive tool materials. However, within the last five years, tool advancements have begun to enable FSW of steels. Polycrystalline boron nitride (PCBN), tungsten-rhenium alloys, and mixtures thereof appear to be capable of producing sound welds in steel. This paper describes the results of a continuing study on the FSW of pipeline steels. Pipe grades from API X65 to X120 were subjected to FSW. Strength and toughness measurements using the crack tip opening displacement test were performed. The weld microstructure was evaluated using optical, scanning electron, and transmission electron microscopy. A computational fluid dynamics model was developed to better understand the effect of process parameters on thermal cycles, strain rates and strain experienced by material in the weld stir zone.

The results indicate that the microstructure and properties of the welds have little dependence on the tool material, while significant variations in properties were observed between steels produced by different manufacturers. In general,obtaining high levels of toughness on par with gas metal arc mechanized girth welds appears difficult when using the FSW process. The results emphasize the need for a better understanding on the role of process parameters on microstructural evolution and weld quality during FSW of pipeline steels.

As a full-scale demonstration of FSW on pipeline steels, several circumferential girth welds were produced in 762 mm (30 inch) diameter X80

pipe. The results of these efforts are discussed.

IPC2010-31523

IMPLICATIONS AND TRENDS IN SMYS BUILT INTO PIPELINES

建立管线规定最小屈服强度的趋势和意义

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ABSTRACT

For many the use of SMYS in conjunction with workingstrength design for pipelines leads to the expectation that the least strength of the joints in the pipeline is at or above SMYS.In contrast, regulations relevant to pipeline operation reference specifications require limited testing to demonstrate the acceptance of pipe joints made from a “heat” of steel, and where such testing fails such specifications admit a retest.Thus, contrary to the expectation of that all joints constructed into a pipeline achieve SMYS, the statistical reality is that some joints can have strengths that fall below this design expectation.This paper considers the implications of changes due to the globalization of the steel and pipe-making industries relative to the historical evolution of classes/grades of steel and their processing in regard to the statistical properties of line pipe built into a pipeline. It is shown for the data evaluated that, in spite of globalization and other aspects that tend to diminish quality such as increasing heat-volume, controls affected in steel and pipe production can lead to better quality today as compared to historical scenarios. Circumstances that can compromise this outcome are identified and discussed.

KEYWORDS: SMYS, API5L, standards, specifications, heat,lot, mill-testing, QC/QA, statistical variability, pipeline, steel,grade

IPC2010-31531

PREDICTIONS OF CLEAVAGE FRACTURE IN WELDED COMPONENTS INCORPORATING STRENGTH MISMATCH EFFECTS: A WEIBULL STRESS BASED APPROACH

不等强匹配焊接件中解理断裂的预测：基于威布尔应力的方法

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ABSTRACT

This work describes the development of a toughness scaling methodology incorporating the effects of weld strength mismatch on crack-tip driving forces. The approach adopts a nondimensional Weibull stress, σw , as a the near-tip driving force to correlate cleavage fracture across cracked weld configurations

with different mismatch conditions even though the loading parameter (measured by the *J*-integral) may vary widely due to mismatch and constraint variations. Application of the procedure to predict the failure strain for an overmatch girth weld made of an API X80 pipeline steel demonstrates the effectiveness of the micromechanics approach. Overall, the results lend strong support to use a Weibull stress based procedure in defect assessments of structural welds.

IPC2010-31532

THE EFFECT OF HOT STRIP MILL PROCESSING PARAMETERS AND ALLOY ADDITION ON LOW TEMPERATURE TOUGHNESS OF API-X70 STEEL

热轧带钢工艺参数和合金添加对API-X70钢低温韧性的影响

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ABSTRACT

Correlation of rolling conditions, microstructure, and low-temperature toughness of X70 pipeline steels was investigated in this study through statistical analysis. High strength API X70 steel grade with excellent DWTT toughness can be designed by the developed statistical equation. The predicted equation is as follows; „Pct Shear area of DWTT (-10ºC) = 954 - 0.3*SRT + 0.5*TBT - 0.4*FRT + 0.04*CT - 306*C -60*(Mn+Ni+Cu) + 38*(Mo+Cr) - 791*(Ti+Nb+V) - 4*MA“ and the predicted equation showed very good relationship. M/A constituent showed high relationship with DWTT toughness. By inserting this effect into the equation, the reliability of the equation has been improved. By using the prediction equation, new chemical composition and relevant processing variables could be optimized and newly designed steel shows proper tensile properties with the excellent DWTT

toughness at -10°C.

IPC2010-31535

ROOT CAUSES FOR FAILURES IN FLATTENING TEST IN HIGH FREQUENCY INDUCTION WELDED STEEL PIPE MILL

高频感应焊管厂压扁试验失败的根源

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ABSTRACT

The aim of the flattening test in a High Frequency Induction Welded (HFIW) steel pipe mill is to test the weld integrity. Failures in the flattening test may cause rejection of tested pipe and additional costs as result of retesting the other pipes from the same coil, scrapping and cutting the tested material, segregating and transporting of pipes required for flattening retest, and delaying the release of material. This paper presents the root causes for failures in the flattening test due to inadequate process control. The paper also discusses the failures in the flattening test associated with the severity and lack of clarity of the acceptance criteria in some of the pipeline international specifications. The targeted specifications are API 5L and ISO 3183. Specifically, the paper proposes, based on practical experience, changes of the acceptance criteria in the international specifications related to the first step of flattening test which is the test of weld ductility.

IPC2010-31547

IMPROVEMENT OF IN-LINE PROCESS CONTROL IN HIGH FREQUENCY WELDED STEEL PIPE MILL USING ADVANCE TUBE TRACKING SYSTEM

高频焊管厂利用先进管道跟踪系统改进在线工艺控制

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ABSTRACT

This study is based on practical experience of improving in-line process control in High Frequency Induction Welded steel pipe mill through the use of a unique advance tube tracking system. The system was designed and implemented in Saudi Steel Pipe Co in early 2009. The new tracking system goes beyond identifying the tube, coil, and heat number. It has the advantage of allowing the quality control inspectors to enter the hold tubes numbers in the system and restrict those hold tubes from processing in the next stages. This has led to significant improvement in segregation process and eliminating the hold pipes from reaching the final stage or the customer site. The tracking system is also linked to the Continues Electronic Process Control (CEPC)

where all the welding and annealing parameters such as welding power, line speed, and annealing temperature are recorded and automatically linked to each produced coil. Furthermore, all in-process inspection reports are entered directly on the system which has resulted in reduction of manual work and availability of huge database for analysis. Engineers, managers, and even third party inspectors have the chance of viewing all inspection reports through the system. They can even check the history of each pipe, when and how many times it was tested and/or held at each station. The full history of each pipe can be obtained using only the find option in the tracking system. A significant improvement was also noticed in reducing manual work in preparation of release documents since all information is available in the system and can be checked and reviewed in a real time basis.

IPC2010-31551

IMPROVED COLLAPSE RESISTANCE OF LARGE DIAMETER PIPE FOR DEEPWATER APPLICATIONS USING A NEW IMPANDER TECHNOLOGY

利用一种新无扩径技术提高深水用大口径钢管破断抗力

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ABSTRACT

Large diameter pipe is most commonly produced by the UOE and JCO processes. In both cases the pipe is finished by cold expansion, which is known to be the main contributor to the reduced collapse pressure of such pipe compared to seamless pipe of the same steel grade and diameter-to-thickness ratio. The main cause of this degradation in collapse pressure is a reduction in the compressive yield strength of the material that results from the cold forming steps involved, particularly the expansion. This paper presents a new manufacturing technology in which longitudinally welded pipe is finished by controlled compression. A newly developed cold sizing press,called Impander, is used to produce pipe that is rounder, has reduced residual stresses, and increased compressive yield strength. The combination of these factors can

lead to a significant increase in the collapse pressure of the pipe. The new technology is first introduced followed by experimental and analytical results that demonstrate the improved collapse pressure of pipes manufactured by it. The enhancement in collapse pressure will be demonstrated using X-65 grade, 20-inch pipe with one-inch wall. Pipes are compressed to different degrees, and their dimensional characteristics and compressive mechanical properties are measured. The measurements are used in finite element models to calculate the collapse pressure demonstrating the improved performance. The advantages of the process will also be confirmed using results from full-scale collapse experiments on 20-inch pipe manufactured by the new process.

IPC2010-31565

EVALUATING MECHANICAL PROPERTIES OF HYBRID LASER ARC GIRTH WELDS

激光电弧复合焊环焊缝力学性能的评价

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ABSTRACT

This paper presents the challenges and results associated with mechanical testing of overmatched X80 and X100 pipeline steel girth welds that were produced by Hybrid Laser Arc Welding (HLAW). The weld profile produced by this process is characterized as having a broad weld cap and a narrow leg, which traverses the through thickness direction.

The development and testing of the HLAW process was conducted on NPS36 pipes of 10.4 mm and 14.3 mm thickness, respectively. The welds were deposited in the 5G welding position with all parameters and laser visual inspection data being collected for each weld pass. Subsequent sample extraction and testing of the hybrid laser arc welds were achieved by standard test practices for girth welds and modifications of these practices, where the latter was required to facilitate testing of the narrow HLAW geometry.

Charpy results indicate that the fracture transition temperature, with the notch in either the weld metal or the heat-affected zone (HAZ), is higher at the 3 and 9 o'clock positions when compared to 9 and 12 o'clock positions. The likelihood of crack deviation influencing the results due to the non-conventional weld geometry needs to be examined in a further study. For crack tip opening displacement (CTOD) testing, shorter fatigue crack lengths were employed to reduce the possibility of fatigue crack deviation. The results show that this method does not influence the validity of the test outcomes.

IPC2010-31572

GASDECOM: CARBON DIOXIDE AND OTHER COMPONENTS

GASDECOM方程: 二氧化碳和其他组分

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ABSTRACT

Carbon dioxide (CO2) pipelines are more susceptible to long running fractures than hydrocarbon gas pipelines because of the decompression characteristics of CO2. The key to understanding this issue is the phase diagram and the liquid-vapour phase boundary.

GASDECOM – based on the BWRS equation of state – is a program widely used for calculating the decompression behaviour of mixtures of hydrocarbons. The calculated decompression wave velocity curve is then used in models such as the Battelle Two Curve Model to determine the toughness required to arrest a propagating ductile fracture. GASDECOM is capable of modelling mixtures of hydrocarbons (methane through to hexane), nitrogen and carbon dioxide. It therefore can (and has) been used to investigate the effect of methane and nitrogen on the decompression characteristics of CO2. Pipelines can be expected to play a significant role in the transportation infrastructure required for the successful implementation of carbon capture and storage (CCS). The composition of the carbon dioxide rich stream to be transported in a pipeline depends on the capture technology, e.g. post-combustion, pre-combustion and oxy-fuel. Post-combustion tends to result in an almost pure stream. The other capture technologies produce a less pure stream, containing potentially significant proportions of other components such as hydrogen, nitrogen, oxygen, argon and methane. One of the factors that will constrain the design and operation of a carbon dioxide pipeline is the effect of these other components on the decompression characteristics, and hence the arrest toughness (amongst other issues). Components such as hydrogen, oxygen and argon cannot currently be considered using GASDECOM.

Through a study of the underlying algorithms implemented in GASDECOM, it is shown how GASDECOM can be modified to include these additional components relevant to carbon capture and storage. The effect of impurities such as hydrogen on the decompression characteristics is then illustrated, and related back to their effect on the phase diagram and the liquid-vapour phase boundary. The sensitivity of the results to the use of equations of state other than BWRS is also illustrated. Simplifications that follow from the decompression behaviour of carbon dioxide are also highlighted.

Finally, the small and large scale experimental studies that are required to validate predictions of the decompression behaviour and the arrest toughness are discussed.

IPC2010-31596

FINITE ELEMENT ANALYSIS OF FIBRE AUGMENTED STEEL TECHNOLOGY PIPE (FAST-PIPETM)

纤维增强钢管（FAST-Pipe™）的有限元分析

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ABSTRACT

The FAST-PipeTM concept involves wrapping a conventional strength steel pipe (e.g. X70), whose thickness is selected to satisfy axial and bending load requirement, with dry fibreglass to achieve the pressure load requirement. FAST-PipeTM offers several technical and economical advantages over high strength steel concepts. Since FAST-PipeTM is a new technology, there is a need to develop analytical methods for its design. This paper describes the finite element analysis (FEA) models used to predict experimental response. The calibration of the FEA models for FAST-PipeTM involved the pressure-strain history, the burst pressure, the moment curvature history and the bending strain capacity of FAST-PipeTM subjected to a combination of internal pressure, axial force and bending.

The finite element program ABAQUS was used to develop shell models capable of simulating the burst and bending behaviour of FAST-PipeTM. Several burst and bend tests performed on 48- and 12-inch pipes were used to verify and calibrate the finite element analysis models. The effects of the type of steel-fibre bond, the thickness of the wrap, the wrap elastic modulus and the steel yield criteria were studied for the bend model. In the main FEA bend models, no bond was assumed to exist between the steel liner and the wrap in the hoop direction, and the steel liner was modelled using an elastic-plastic, kinematic hardening material model with an initially shifted yield surface. The failure of both the burst and bend models was defined as the point where the wrap hoop strain reached a failure strain of about 2%.

The implementation of the FEA burst model was validated based on the burst test results. The assumption of no bond in the hoop direction and full bond in other directions resulted in reasonable predictions of the bending strain capacity. The autofrettage process influenced only the initial part of the moment-curvature response of a FAST-PipeTM by producing a stiffer response, without significantly affecting the bending strain at failure and moment capacity. The wrap elastic modulus value and the type of yield criteria used for the steel liner had no significant effect on the moment capacity reached by the FEA models.

IPC2010-31602

MECHANICAL PROPERTIES AND COMPONENT BEHAVIOUR OF X80 HELICAL SEAM WELDED LARGE DIAMETER PIPES

大口径X80钢级螺旋焊管线管的力学性能和成分

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ABSTRACT

The paper discusses the development and processing of hot rolled X80 coil material and its conversion into thick-walled helical seam welded pipes. Microstructure, texture and mechanical properties of strips and pipes produced are characterized and compared. High strength characteristics and good deformability as a result of the fine homogenous mainly bainitic microstructure have been determined. Stress strain characteristics and the response to cold deformation during pipe forming have been investigated. Correlations between strip and pipe properties are described and have been used as a data basis for FEM simulations of the pipe forming process. The real pipe behavior has been investigated by means of burst tests performed on 48” and 42” pipe sections with 18.9mm wall thickness. The results achieved have been compared with results for other pipe grades, dimensions and types of pipe. An outlook will be given on future material and process development steps and use of X80 HSAW-pipes produced.

IPC2010-31608

AUTOMATED LASER ULTRASONIC INSPECTION OF HYBRID LASER ARC WELDING FOR PIPELINE CONSTRUCTION

管线建设中激光电弧复合焊的自动激光超声波检测

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ABSTRACT

Hybrid laser arc welding (HLAW) is a technology that promises to increase the efficiency of welded fabrication. By incorporating automation, and integrating an automated inspection system, HLAW can produce high quality welds at higher production rates and lower costs compared to even the most advanced pipeline welding system that is in use today. As the HLAW technique is developed and implemented for pipeline construction, it is important to develop an associated automated technique for weld inspection. We have applied automated laser ultrasonic testing (ALUT) to the important requirement of the in-line monitoring of new HLAW welds in the field. Laser ultrasonic testing (LUT) offers the advantage of true in-process measurement, providing immediate information on weld integrity. In this paper, we will describe our efforts to apply LUT to pipeline girth weld inspection. The technology development process and the integration into an HLAW system will be described.

IPC2010-31627

ENGINEERING CRITICAL ASSESSMENT IN THE COMPLEX GIRTH WELDS OF CLAD AND LINED LINEPIPE MATERIALS

双金属复合管线管的复杂环焊缝的临界状态评估

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ABSTRACT

The nature of aggressive hydrocarbon reservoir fluids places demands upon material selection for linepipe that can only be met by the use of corrosion resistant alloys (CRAs):either in solid form; or as an internal liner or clad layer combined with a carbon steel substrate. Design and construction guidance for such flowline systems is presently not comprehensive in offshore pipeline standards, even for cases where the CRA layer could be ignored in terms of structural design. Offshore pipelines designed and fabricated in accordance with DNV OS-F101 benefit from the standard allowing flaw

acceptance levels for girth welds to be determined based on an engineering critical assessment (ECA).

The linepipe materials presently available fall into two main categories: clad, where the CRA layer is metallurgically bonded to the carbon steel substrate; and lined, where the CRA liner is mechanically bonded in place within the carrier pipe.These products present a mixture of common and unique challenges when designing and welding flowlines. In particular,the welds in these materials are typically more complex than in rigid C-Mn flowlines and this fact is reflected in the difficulty in conducting ECAs using the available conventional guidance.Due to production limitations on linepipe dimensions, it may also be necessary to explicitly take account of the strength of the clad layer in the overall design, including assessing integrity and fracture control across the full (composite) wall thickness.

This paper discusses conducting ECAs in such complex weldments whilst addressing the implications of these challenges. Reference is made to experience gained from two projects; where, in the most recent of these (the Deep Panuke project), new guidance on conducting such ECAs has been implemented for the first time. The Deep Panuke flowlines comprise: four 8in production flow-lines in clad pipe with a 12.5mm WT grade 415 (X60) carbon steel substrate and an internal 2.5mm Incoloy Alloy 825 clad layer; and a single 3in acid gas flowline in solid Inconel Alloy 625. Both lines will be welded by manual GTAW using 686 filler material. The nominal level of installation plastic strain for the project ranges up to 1.7% in the case of the 8in line so the additional complexities of cyclic plastic deformation during installation must also be addressed by the ECA using constraint-matched SENT fracture mechanics specimens and a tearing instability fracture assessment.

The challenge of achieving adequate strength in the weld is ever-present but the intrinsic yield strength limitations of CRA materials makes the probability of an undermatching condition high enough (despite a strong focus during weld procedure development) that the ECA philosophy has to be able to accommodate a potential weld undermatching condition.Broadly speaking, the strategy adopted is to use finite element analysis (FEA) to model the crack driving force (in terms of J or CTOD) of a flaw in an undermatched weld used in order to support and, where necessary, calibrate BS7910 type fracture mechanics assessments. The assessment will thus be fine-tuned to account for the actual level of undermatch present. The methodology is a new one and is a first for the Deep Panuke project. A case study from an earlier project on lined pipe is also presented for comparison.

IPC2010-31629

REALITY CHECK ON GIRTH WELD DEFECT ACCEPTANCE CRITERIA

环焊缝缺陷的验收标准的实现状研究

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ABSTRACT

This paper examines the inherent conservatisms of alternative girth weld defect acceptance criteria from the 2007 API 1104 Appendix A, CSA Z662 Appendix K, and the proposed EPRG Tier 2 criteria. The API and CSA codes have the same empirical limit-load criteria, where it has previously been shown that the conservatism on the failure stress is ~30 to 50 percent compared to pipe test data prior to applying any safety factors. In terms of flaw length, it was found that the API/CSA limit-load equation might allow a flaw of 5% of the pipe circumference, where the properly validated limit-load equation would allow a flaw of 75% of the circumference, i.e., a safety factor of 30 percent on load corresponded to a safety factor of 15 on flaw length for that example case.

Similarly there are conservatisms in a proposed EPRG Tier 2 girth weld defect acceptance criterion. This proposed criterion was directly based on curved-wide-plate data to assure that toughness was sufficient to meet limit-load conditions for a curved-wide plate. However, the curved-wide plates are really an intermediate-scale test, and still require proper scaling to pipes of different diameters. The proposed Tier 2 EPRG allowable flaw length is 7T from a large database of curvedwide-plate tests with the a/t value of less than 0.5 (or a < 3mm),and the failure stress being equal to the yield strength of the base metal (also requires the weld metal overmatch the base metal strength, and the Charpy energy at the defect location have a minimum > 30 J and average > 40 J). However, the widths of those curved-wide-plate tests are typically a factor 5 to 12 times less than typical large-diameter pipes. The proper limit-load/fracture mechanics scaling solution would have the flaw length proportioned to the plate width, not the specimen thickness. Additionally, the proper limit-load solution for a pipe in bending gives a much larger tolerable flaw size at the yield stress loading than a plate or pipe under pure tension. Example calculations showed that the EPRG Tier 2 approach is conservative on the flaw lengths by approximately 9 for pure axial tension loading, and between 34 to 79 for a pipe under bending.

Suggestions are presented for an improved procedure that accounts for proper limit-load solutions for pipe tests, effects of pipe diameter, effects of internal pressure, and also a much simpler approach to incorporate the material toughness than the 2007 API 1104 Appendix A Option 2 FAD-curve approach. The fracture analyses could evoke SENB, SENT testing, or have relatively simple Charpy test data to assess the transition temperatures to ensure ductile initiation will occur.

IPC2010-31634

Improvements to Rich Gas Decompression Predictions for Offshore Pipelines

海洋管线富气减压预测的进步

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Abstract

This paper describes how rich gas decompression predictions have been performed for use in the Battelle-Two-Curve ductile fracture model for application to offshore pipelines. The decompression behavior of rich gases in offshore pipelines is more complicated than for onshore pipelines for two major reasons, (1) the operating pressures typically are greater offshore than onshore, and (2) the effects of higher molecular weight components in rich gases are not well described by earlier methods. Although for lean gases the AGA8 method is very accurate for single phase gas and the GASDECOM method is reasonably accurate for gases which enter the two phase region, neither of these existing methods is sufficiently accurate for two phase conditions for gases containing more than about one mole percent hexanes and heavier hydrocarbons at pressures greater than about 15 MPa. This paper discusses the requirements for a method to achieve sufficiently accurate high pressure rich gas decompression predictions for use in the Battelle-Two-Curve ductile fracture model and provides examples of the use of an interim method which has suggested the path to an ultimate solution.

IPC2010-31636

DEVELOPMENT OF X100 ON COIL AND FIRST WELDABILITY ASSESSMENT

X100卷板的研究及第一次焊接性评定

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ABSTRACT

The development of X100, 13mm thick, on coil at ArcelorMittal is on schedule. Different steel compositions grouped in different categories A, C, D with various alloying contents and carbon equivalents have been tested by means of appropriate laboratory simulations. From these simulations, two different concepts have been developed, able to fulfil X100 strength properties

in combination with excellent low temperature toughness. These two concepts are suited for low or high coiling temperatures (Type C and D respectively). The influence of the different TMCP (Thermomechanical controlled processing) parameters on the strength-toughness properties is shown and explained by the various microstructures. The low coiling temperature concept is based on a fine granular bainite microstructure avoiding the presence of M/A constituent and providing an excellent combination of strength and toughness.The high coiling temperature concept exhibits a quasipolygonal ferrite microstructure with M/A as second phase. The M/A constituent seem to strengthen the steel without impairing the toughness while the quasi-polygonal ferritic matrix retains excellent toughness. A first assessment of the weldability has been done through the simulation and analysis of the heat affected zone for different cooling times between 800 and 500°C. The concept with a lower carbon equivalent (Type D) gives excellent weldability results.

IPC2010-31640

EPRG TIER 2 GUIDELINES FOR THE ASSESSMENT OF DEFECTS IN TRANSMISSION PIPELINE GIRTH WELDS

欧洲钢管研究小组对输送管线环缝缺陷的评价2级指导方针

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ABSTRACT

This paper presents the proposed revisions of the EPRG guidelines for the assessment of defects in transmission pipeline girth welds. The revisions cover Tier 2 of the guidelines, in particular (a) the extension of the guidelines to include Grade L555 (X80) material, (b) the assessment of surface-breaking defects with heights up to 5mm and (c) the assessment of multiple co-planar defects. Since the welds should be, at least, matching the pipe material in yield strength,the paper also defines the required levels of weld metal yield strength for the safe application of the guidelines.

IPC2010-31643

A COMPARISON OF TWO MAJOR LINEPIPE SPECIFICATIONS AND POSSIBILITIES FOR HARMONIZATION

管线钢两个主要规范之间的对比和协调的可能性

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ABSTRACT

A fundamental building block of all pipeline systems is the linepipe used to construct the pipeline. The specification for this pipe is the means of ensuring that the designer's and owner's requirements are communicated to the pipe mill and then ensuring that the correct pipe is delivered. The most widely used specification is probably API 5L; this has recently been harmonized with the corresponding ISO specification,ISO 3183:2007. Within Europe, EN 10208-2 has been widely used, particularly for onshore gas transmission pipelines. This standard was revised in 2009. There are presently differences between these specifications. Development of a single document could reduce costs for producers and users, as all parties will be working from a common baseline and a wider range of markets and sources of material will be available.

The European Pipeline Research Group (EPRG) has carried out a comparison of the harmonized API/ISO and the EN specifications. This was intended to assist the drafting committees in working towards a single standard without compromising safety or increasing costs. The study has identified the areas of agreement and differences between the documents. The results of this comparison are presented in this paper, including recommendations for changes to achieve the goal of a common specification. The implications of possible changes for costs and safety are also considered.

IPC2010-31665

YIELD STRENGTH OF LINE PIPE – ANALYSIS OF FORMING OPERATIONS AND FLATTENED STRAPS

管线管的屈服强度:对成型操作和钢带压平的分析

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ABSTRACT

The effects of line pipe forming processes(Spiral, UOE, JCE, 3 Roll Bending, ERW) on steel yield strength are investigated by material modeling and mechanical testing. A model is developed for predicting the performance of a flattened transverse-body-tensile sample as typically performed by pipe mills for yield strength determination. Consideration is given to the Bauschinger effect, and hardening behavior to examine the resulting residual stress patterns through the wall thickness and the effect on measured yield strength. The pipe forming processes are modeled as pure bending and analyses are performed to determine how well this assumption simulates the actual operations.Tensile and compression testing is performed to establish the Bauschinger effect in both the tension and compression initial loading directions. The tensile data is incorporated into the material model. The model illustrates the progressive evolution of the residual stress pattern throughout the sequence of forming operations and specimen preparation. In addition, the residual curvature remaining in flattened tensile samples is analyzed and correlated with mechanical tests. The apparent modulus caused by curvature is shown to cause significant variation in the reported yield strength of linepipe.
Keywords: line pipe, yield behavior, forming,yield surface, Bauschinger effect, biaxial stress,helical seam pipe

IPC2010-31667

Effects of Pipe Internal Surface Roughness on Decompression Wave Speed in Natural Gas Mixtures

钢管内表面粗糙度对天然气混合物减压波速度的影响

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Abstract

The control of propagating ductile (or tearing) fracture is a fundamental requirement in the fracture control design of pipelines. The Battelle two-curve method developed in the early 1970s still forms the basis of the analytical framework used throughout the industry. GASDECOM is typically used for calculating decompression speed, and idealizes the decompression process as isentropic and one-dimensional,taking no account of frictional effects. While this approximation appears not to have been a major issue for large-diameter

pipes and for moderate pressures (up to 12 MPa), there have been several recent full-scale burst tests at higher pressures and smaller diameters for which the measured decompression velocity has deviated progressively from the predicted values, in general towards lower velocities. The present research was focused on determining whether pipe diameter was a major factor that could limit the applicability of frictionless models such as GASDECOM.Since potential diameter effects are primarily related to wall friction, which in turn is related to the ratio of surface roughness to diameter, an experimental approach was developed based on keeping the diameter constant, at a sufficiently small value to allow for an economical experimental arrangement, and varying the internal roughness. A series of tests covering a range of nominal initial pressures from 10 to 21 MPa, and involving a very lean gas and three progressively richer compositions, were conducted using two specialized high pressure shock tubes(42 m long, I.D. = 38.1 mm). The first is honed to an extremely smooth surface finish, in order to minimize frictional effects and better simulate the behaviour of largerdiameter pipelines, while the second has a higher internal surface roughness. The results show that decompression wave speeds in the rough tube are consistently slower than those in the smooth tube under the same conditions of mixture composition and initial pressure & temperature.Preliminary analysis based on perturbation theory and the fundamental momentum equation indicates that the primary reason for the slower decompression wave speed in the rough tube is the higher spatial gradient of pressure pertaining to the decompression wave dynamics, particularly at lower pressure ratios and higher gas velocities. The magnitude of the effect of the slower decompression speed on arrest toughness was then evaluated by a comparison involving several hypothetical pipeline designs, and was found to be potentially significant for pipe sizes DN450 and smaller.

IPC2010-31678

DESIGNING CO_2 TRANSMISSION PIPELINES WITHOUT CRACK ARRESTORS

怎样设计无止裂器的CO2管线

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ABSTRACT

Masdar is developing several carbon capture projects from power plants, smelters, steel works, industrial facilities and oil and gas processing plants in Abu Dhabi in a phased series of projects. Captured CO2 will be transported in a new national CO2 pipeline network with a nominal capacity of 20x106 T/y to oil reservoirs where it will be injected for reservoir management and sequestration.

Design of the pipeline network considered three primary factors in the

selection of wall thickness and toughness, (a) steady and transient operating conditions, (b) prevention of longitudinal ductile fractures and (c) optimization of total project owning and operating costs.

The paper explains how the three factors affect wall thickness and toughness. It sets out code requirements that must be satisfied when choosing wall thickness and gives details of how to calculate toughness to prevent propagation of long ductile fracture in CO2 pipelines. It then uses cost optimization to resolve contention between the different requirements and arrive at a safe and economical pipeline design.

The design work selected a design pressure of 24.5 MPa,well above the critical point for CO2 and much higher than is normally seen in conventional oil and gas pipelines. Despite its high operating pressure, the proposed network will be one of the safest pipeline systems in the world today.