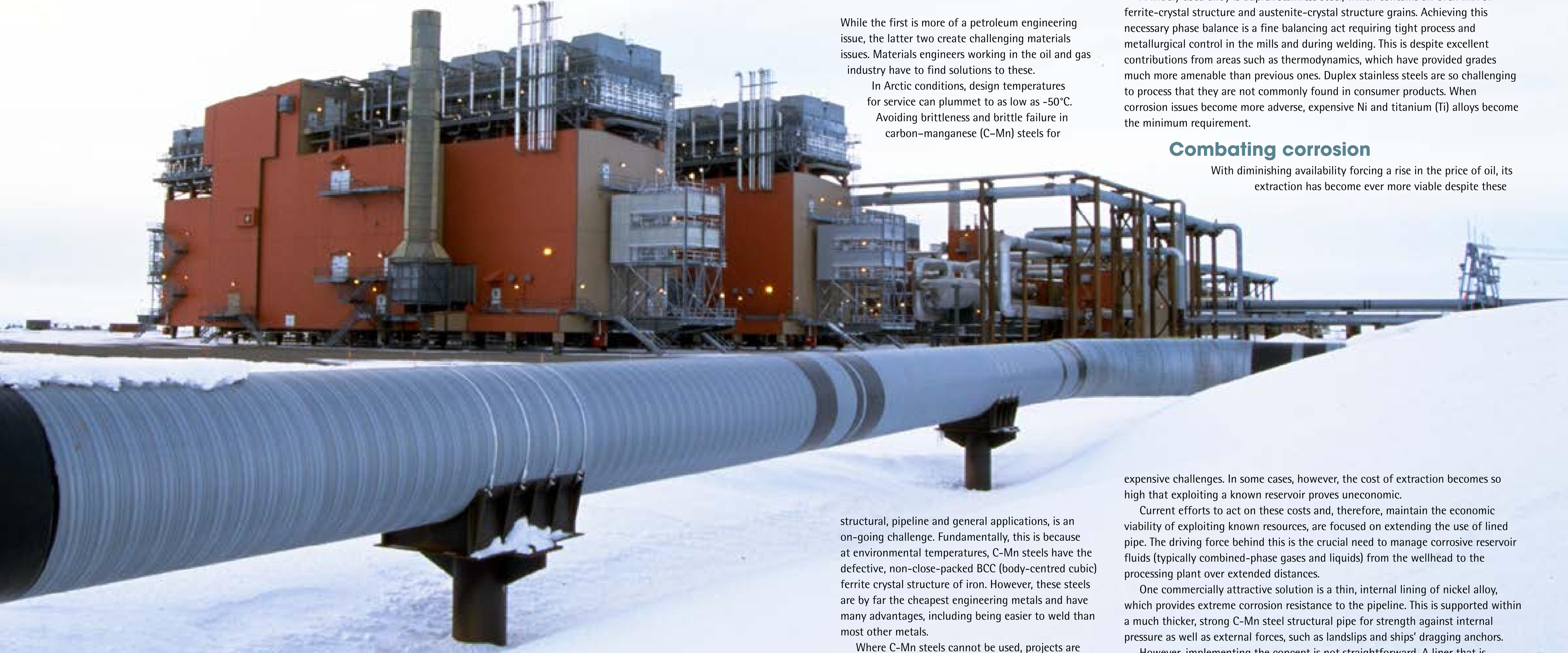
Pipe down

Is the subsea industry any closer to solving the materials challenges it currently faces? **Andrew Low**, Deputy Engineering and Technology Manager at INTECSEA, UK, examines the issues and potential solutions.



Hydrocarbon resources, the most desirable oil qualities that are most accessible onshore, are now largely depleted. The challenges currently faced by the oil and gas industry are to provide energy needs by extracting resources that are:

- expensive to extract – such as tar sands, hydraulic fracturing (fracking) of shale-beds
- less accessible – deepsea, high in the Arctic
- of undesirable grade/composition

While the first is more of a petroleum engineering issue, the latter two create challenging materials issues. Materials engineers working in the oil and gas industry have to find solutions to these.

In Arctic conditions, design temperatures for service can plummet to as low as -50°C. Avoiding brittleness and brittle failure in carbon–manganese (C–Mn) steels for structural, pipeline and general applications, is an on-going challenge. Fundamentally, this is because at environmental temperatures, C-Mn steels have the defective, non-close-packed BCC (body-centred cubic) ferrite crystal structure of iron. However, these steels are by far the cheapest engineering metals and have many advantages, including being easier to weld than most other metals.

Where C-Mn steels cannot be used, projects are generally not commercially viable. Tight control of the steel's microstructure, both at the mill and during welding, ensures that the onset of brittleness occurs at temperatures below those at operating conditions. Obtaining this toughness in Arctic-grade steels is a tough challenge that is battled – with great success – by technologists.

Alloy, alloy

Extracting hydrocarbon resources with undesirable impurities generates severe corrosion-control issues. Soured hydrocarbon reservoirs contain acids and hydrogen sulphide, which work together in several destructive ways against metals. Combined with high-chloride brines and other impurities emerging from the hydrocarbon reservoirs, at elevated temperatures (often over 100°C) corrosion conditions are severe – more severe, in fact, than could be endured by standard 'teapot' stainless steel. Typically, austenitic 308 grades containing 18% chromium (Cr) and 10% Nickel (Ni) balance the iron (Fe) content, hence the common name '18/10'.

A widely used alloy is duplex stainless steel, which contains an even mix of ferrite-crystal structure and austenite-crystal structure grains. Achieving this necessary phase balance is a fine balancing act requiring tight process and metallurgical control in the mills and during welding. This is despite excellent contributions from areas such as thermodynamics, which have provided grades much more amenable than previous ones. Duplex stainless steels are so challenging to process that they are not commonly found in consumer products. When corrosion issues become more adverse, expensive Ni and titanium (Ti) alloys become the minimum requirement.

Combating corrosion

With diminishing availability forcing a rise in the price of oil, its extraction has become ever more viable despite these expensive challenges. In some cases, however, the cost of extraction becomes so high that exploiting a known reservoir proves uneconomic.

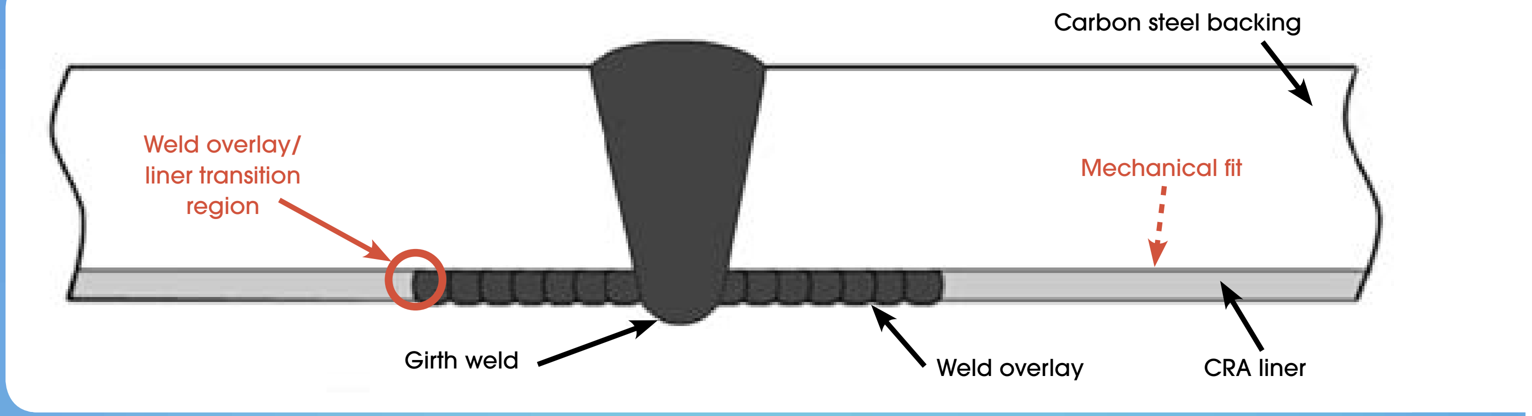
Current efforts to act on these costs and, therefore, maintain the economic viability of exploiting known resources, are focused on extending the use of lined pipe. The driving force behind this is the crucial need to manage corrosive reservoir fluids (typically combined-phase gases and liquids) from the wellhead to the processing plant over extended distances.

One commercially attractive solution is a thin, internal lining of nickel alloy, which provides extreme corrosion resistance to the pipeline. This is supported within a much thicker, strong C-Mn steel structural pipe for strength against internal pressure as well as external forces, such as landslips and ships' dragging anchors.

However, implementing the concept is not straightforward. A liner that is metallurgically attached through processes such as weld-cladding or explosion bonding gives a pipeline with good performance, but is expensive and slow to produce. Therefore, as technology currently stands this is not an economically viable option for long pipelines.

A less expensive option is to line a C-Mn steel pipe with a thin, tubular liner made from a corrosion-resistant alloy. This can be attached to pipe via readily available manufacturing techniques that involve expanding the pipes to mechanically grip the liner. Pipe joints are finished with short lengths of corrosion-resistant weld overlay at the pipe ends that can be easily accessed (see below). This overlay:

- continues the CRA to the pipe-end, where the weld metal will butt-join the pipelengths
- seals the end of the mechanical liner, denying access of the well fluid to the C-Mn steel structural substrate
- acts as a structural weld at the liner ends, joining the liner to the pipe



Fighting fatigue

While this method looks to be economically viable, one serious engineering question remains – how will such a pipeline perform in flexure-fatigue? This uncertainty is currently addressed by a conservative approach to fatigue design of lined pipes.

The viability of using mechanically-lined pipe hangs on knowing whether the weld overlay/liner transition point is a fatigue critical detail. From the diagram above, it can be seen that the three-way joining of the CRA liner, the C-Mn structural steel and the CRA overlay creates a geometric notch. In metal fatigue and fracture mechanics, these notches can have high local stress fields associated with initiating fatigue cracks.

In principle, if the elastic grip between the liner and pipe is good enough that the strains and stresses of flexure are uniformly transmitted along the length of the pipe, fatigue life could be good – though given other uncertainties there is no predictable guarantee of this.

If the grip between the liner and the steel pipe is insufficient that the various stresses produce slippage, frettage might be expected. Furthermore, forces generating high levels of stress might be expected at the geometric notch, where the weld overlay acts as a structural weld. In this case, it is unlikely that the pipeline would have good fatigue properties against flexure.

The answers to these questions will make or break the economic viability of exploiting some known hydrocarbon resources. Searching for the answers is a group of scientists at global research and technology organisation TWI, who are running a project with INTECSEA and the support of member companies. It is hoped that full-scale physical testing can solve these unanswered questions on the fatigue performance of mechanically CRA lined pipelines.

Poor defect resolution of ultrasonic testing inherent to coarser-grained austenitic (face-centred cubic crystal structure) metals typical of the liner CRA suggests that if fatigue cracking were to occur in the liner metal, early detection would be difficult. As such, investigative efforts are currently focused on finding non-destructive methods of detecting onset of fatigue cracking at the liner-overlay-steel junction. Artificial defects have been created in test model mechanically-lined pipe to evaluate inspection methods. How close the industry is to addressing these challenges remains uncertain, but progression is being made, with full-scale testing of welded lengths of mechanically lined pipe is scheduled to start in early 2013.

For more information, please contact Andrew Low, andrew.low@intecsea.com