Cold cracking, consumables and high yield strength steels

Alain Laurent, business developer and welding metallurgist for Lincoln Electric's Oerlikon brand of welding consumables, talks to *African Fusion* about the company's consumable range for welding modern high yield strength steel (HYSS).

Products such as heavy mobile equipment; mobile, harbour and ship cranes and steel structures in the petrochemical, oil and gas and offshore industries are making increasing use of modern steels with high yield strength. "There is no real definition of a high yield strength steel, but it is generally accepted to refer to steels with a yield strength greater that 450 MPa and we are now looking at welding steels that yield at 690 MPa and higher," says Laurent.

The crane and lifting industry, which needs the highest strengths possible while keeping the weight to a minimum, is one of the development drivers for these new steels. "Without compromising quality and safety, these steels enable the mass and volume used to be reduced, which significantly reduces the costs of the structures involved," he tells *African Fusion*.

"When welding these steels, however, we need to take precautions in order to prevent hydrogen-induced cold cracking," he says.

Preventing cold cracking

Three key factors combine to cause cold cracking: The first is the internal stress caused by restraint while welding, which is linked to the weld profile, most notably the thickness of the section. "As a consumable manufacturer, we can't do very much to mitigate against this factor," says Laurent.

"The second factor is the microstructure of the weld and heat-affected zone (HAZ), says Laurent, displaying a weld macrograph with a martensitic appearance in the HAZ. "When high cooling rates or quenchability prevail during and after welding, then brittle microstructures can form, which can easily become crack initiation sites," he explains. "Here, the solution is to carefully control the heat input while welding, along with preheat and interpass temperatures and, after welding, the cooling rate," he advises.

The third factor is hydrogen itself, which can be controlled via consumable design, by limiting the hydrogen level remaining in welding consumables after manufacture, preventing atmospheric hydrogen entering the flux through moisture pick-up, as well as mitigating against atmospheric conditions such as relative humidity and moisture on metal plates.

In almost all cases, low hydrogen consumables must be used when welding these steels in order to keep the levels of diffusible hydrogen in the weld metal and HAZ after welding below the crack initiating threshold.

Oerlikon manufactures an advance range of consumables for shielded metal arc welding (SMAW), submerged arc welding (SAW), flux-cored arc welding (FCAW) and solid wires for gas metal arc welding (GMAW) that have been carefully designed to help fabricators to overcome cold cracking problems. "In particular, we have recently released some advanced seamless flux-cored wires that are ideally suited to automatic welding in the offshore, petrochemical and heavy construction sectors," he notes.

Oerlikon consumables have been optimised to reduce impurities and diffusible hydrogen in order to more efficiently overcome the cold cracking hazard.

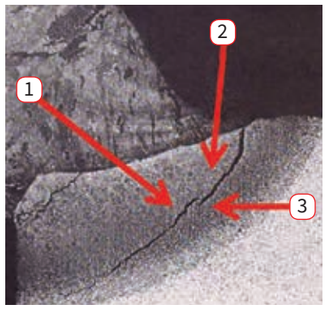
Focusing on the link between diffusible hydrogen (DH) in weld metal and the consumable, Laurent says that the hydrogen source can be induced by different parameters, but the consumable's humidity content is the principle source.

He points to a graph showing how diffusible hydrogen in weld metal increases when consumables used are exposed to atmospheric humidity after removing the wrapping. In relative humidity (RH) of 80% at 27 °C, low-hydrogen consumables will contain over 11 g of moisture – the level associated with 5.0 ml/100 g of diffusible hydrogen in the weld metal – in less than 10 minutes. And within 90 minutes, 18 g of moisture, leading to between 7.0 and 9.0 g of diffusible of hydrogen will be absorbed.

Hence the need to be vigilant about the atmospheric conditions and the exposure times of consumables in those conditions after packages are opened, "to keep moisture pick-up as low as possible".

Oerlikon solutions to help fabricators control moisture pick up include: Dry bag packaging for SAW fluxes; and vacuum packed medium and micro packaging for its SMAW electrodes, which have 24-hour permeability values of less than 0.005 g/m². "In formulating sub-arc fluxes, electrode coatings and flux-cores, we strive to use raw materials with low hydroscopic levels, along with industrial baking procedures that expel moisture," notes Laurent.

Lifting out the Oerlikon range of seamless flux-cored wires, he says that vacuum packaging is not necessary, since an impermeable metal sheath protects the flux. "Seamless cored technology is ideal for welding HYSS, because there is no folded seam to allow moisture to enter the flux," he notes.



The three key factors contributing to hydrogen cold cracking are, 1: microstructure brittleness, often caused by rapid cooling rates; 2: The stress cause by restraint, particularly in thick section weld joints; and 3: the diffusible hydrogen level in the weld metal and heat-affected zones.

Oerlikon consumables for HYSS

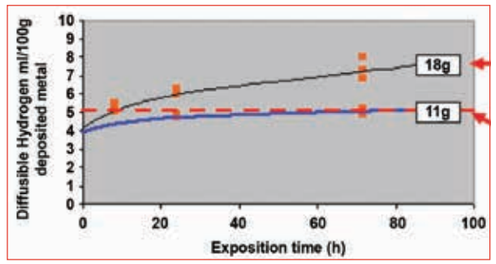
Highlighting its purpose-designed range of consumables for welding high strength steels, Laurent begins with Oerlikon's TENACITO 80CL double-coated stick electrode innovation, which has a current-conducting coating enclosed by an additional non-current-conducting 'cover'.

"This is an excellent technology with many advantages. It is less sensitive to magnetic arc blow, more tolerant to poor joint preparation – narrow bevels, wide root gap, badly aligned plates – offers less porosity and undercut and better penetration," he says.

"In particular, for vertical-up welding where the root gap is wide, the double coated electrode performs exceptionally well. The non-conductive external coating has a containing effect on the welding arc, making it easer for the welder to direct the arc exactly where needed," Laurent explains.

The second innovation he lifts out is the company's basic agglomerated flux for SAW, the OP121TT(H). "This basic flux shows the best compromise for HYSS welding, due to its ultra-low oxygen levels. With a basicity index of 3, weld metal oxygen percentages can be contained at less than 0.03%, which leads to better toughness and Charpy V-notch test results.

Thirdly, though, is Oerlikon's flagship seamless flux-cored wire range of consumables, designed to meet the need for high productivity without compromising weld quality. "Thanks to seamless technology, we not only have a sealed solution that offers very low levels of diffusible hydrogen, but the copper coated sealed wire also improves wire feeding, removing the risk of seams opening under the wire-feed rollers.



A graph showing how exposure of a welding consumable to moisture in the atmosphere affects the diffusable hydrogen level in deposited metal.

"The copper coating improves conductivity and arc stability and protects the wire from corrosion. The seamless sheath also makes the wire stronger with respect to bending and torsion effects, which extends feedability lengths and stability," he adds.

A full range of flux-cored wires is available, with the rutile types being best for welding in position. "The FLUXOFIL brand denotes seamless technology and it complements Oerlikon's CITOFLUX range of folded flux-cored wires. Depending on the weld properties required, we offer consumables for welding steels with yield strengths of up to 745 MPa with acceptable Charpy-V-notch values down to –60 °C," Laurent tells *African Fusion*. "To achieve high yield strength is easy, but to couple high yield with good toughness is very difficult. Oerlikon took on this challenge and now has several suitable consumables," Laurent says.

A new seamless technology

At the cutting edge of Oerlikon's seamless flux-cored wire consumable range is the new-technology seamless wire developed for offshore applications "where toughness is paramount".

Formulated for use with mixed gas (M21) and CO_2, respectively, Oerlikon's FLUXOFIL 22 HD and FLUXOFIL 23 HD are new seamless rutile flux-cored wires for welding fine-grained steels with yield strengths of up to 460 MPa, while delivering reliable toughness behaviour down to –60 °C that comply with NACE requirements.

"At the heart of this technology is a thinner sheath thickness, which allows for a higher core filling ratio and a higher deposition rate. From a hydrogen perspective, diffusible hydrogen in weld metal can be kept below 3.5 ml/100 g using these consumables, which reduces cold cracking risks to below that of traditional seamless cored wires," Laurent notes.

"And all of the feedability and current transfer advantages associated with solid wires apply, due to the optimised copper coating," he adds.

Concluding, Laurent says that Oerlikon consumables have been optimised to reduce impurities and diffusible hydrogen in order to more efficiently overcome the cold cracking hazard and to transfer the necessary weld metal chemical composition and microstructure to the fusion and heat-affected zones.

"By systematically reducing key impurities, these consumables enable fabricators to successfully overcome the difficult compromise of achieving both high yield strengths of 690 MPa while retaining acceptable –60 °C Charpy toughness values," he assures.

	E71T1	E81T1	E91T1	E101T1	E111T1	E121T1
-30 °C	FLUXOFIL 4HD FLUXOFIL 9HD					
-40 °C		FLUXOFIL 21HD			FLUXOFIL 29HD	
-50 °C		CITOFLUX R83C	CITOFLUX R550	CITOFLUX R620Ni2		
-60 °C		FLUXOFIL 22HD FLUXOFIL 23HD				CITOFLUX B690C
Ys (MPa)	> 400	> 470	> 540	> 610	> 690	> 745

A summary of the Oerlikon flux-cored consumable range for welding HYSS while producing good Charpy toughness results. FLUXOFIL: seamless technology; CITOFLUX: folded technology.