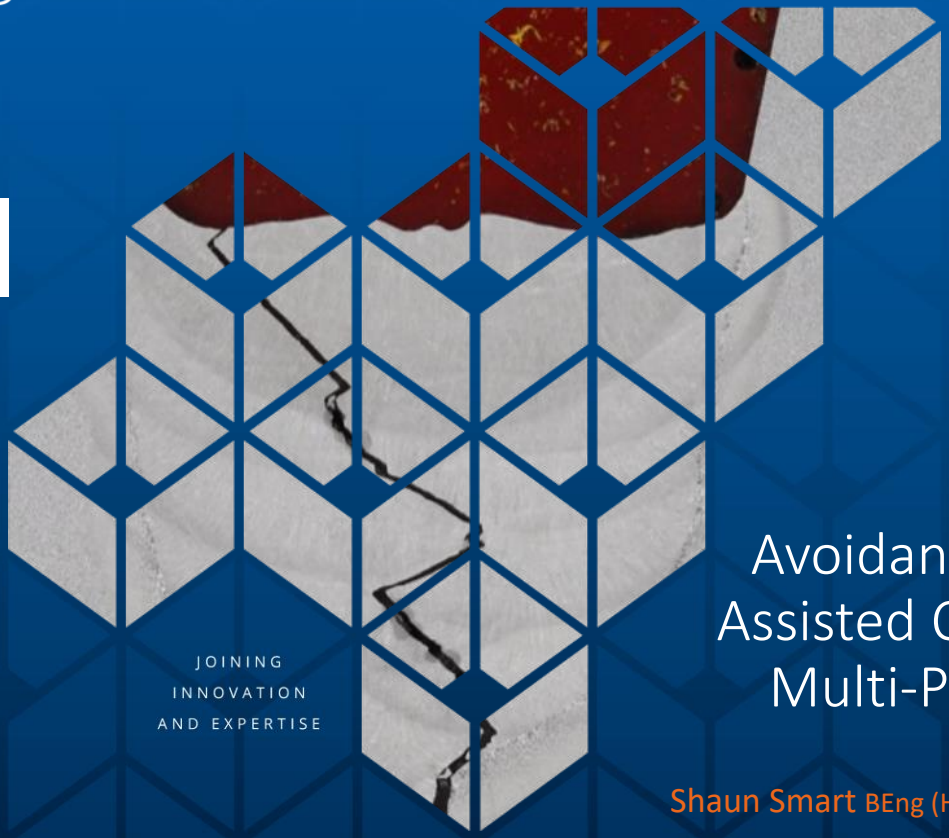

Avoidance of Hydrogen Assisted Cold Cracking in Multi-Pass Weld Metal

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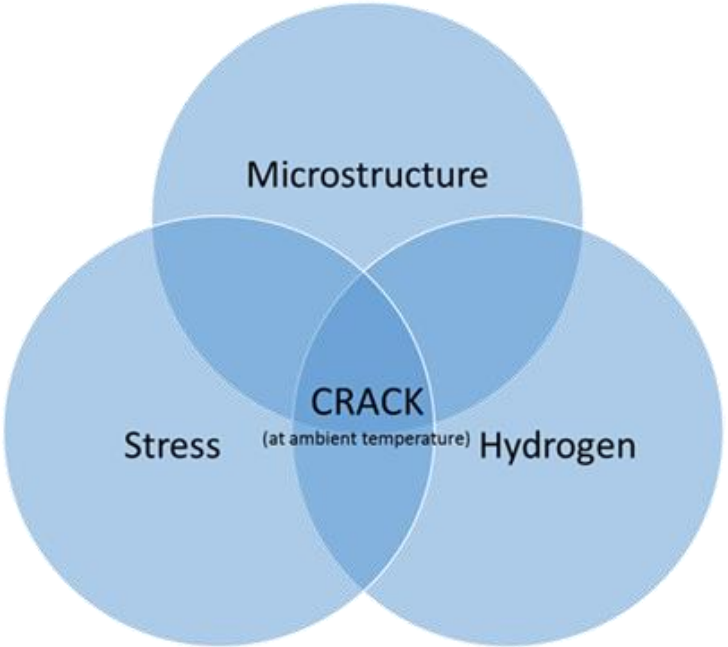
Introduction



- Hydrogen assisted cold cracking (HACC): one of the primary causes of failure during welding.
- Historically hydrogen cracking in the **heat affected zone (HAZ)** has been the predominant mechanism.
- A new challenge due to **weld metal cracking** in lean composition, high strength steels and use of highly alloyed welding consumables.
- Industrial techniques for avoidance of hydrogen cracking are still focused on HAZ cracking and do not fully consider the differences between the **two mechanisms**.
- A need has arisen for creation of controls specific to the avoidance of **weld metal hydrogen cracking**.

Industrial Need - Guidance in Standards

"In general, welding procedures selected to avoid heat affected zone hydrogen cracking will also avoid cracking in the weld metal. However, under some conditions such as high restraint, low carbon equivalent (CE) steels, thick sections, or alloyed weld metal, weld metal hydrogen cracking can become the dominant mechanism" – BS EN 1011-2: 2001

"There has been insufficient research on this problem to include it in the present guidelines, and in such cases testing may be necessary" – AWS D1.1: 2015

Main Objectives

- Establish a repeatable method for producing welds with suitably high concentrations of diffusible hydrogen to initiate HACC.

- Define economical procedural controls for **avoidance of weld metal hydrogen cracking** and present them in a way that is useful to industry.

Literature Review

TWI's Weldasearch and Scopus search engines. Topics covered include:

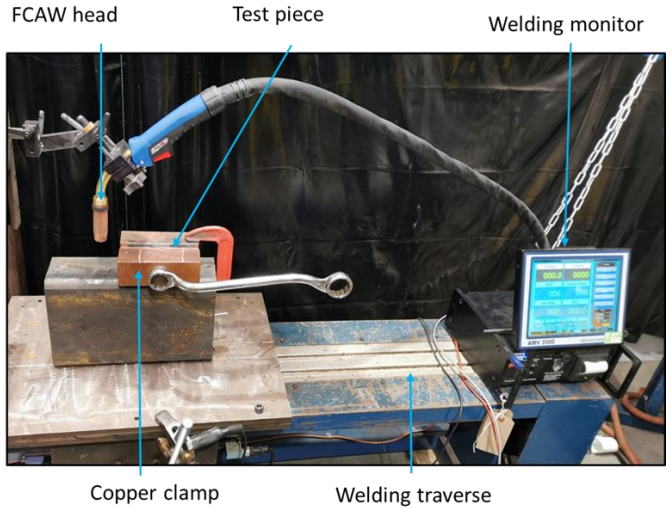
- Heat affected zone and weld metal hydrogen cracking overview;
- Industrial case studies;
- Current industry advice for controlling weld metal hydrogen cracking;
- Crack morphology;
- Weld metal hydrogen cracking testing techniques;
- Weld metal cracking mechanisms:
  - Hydrogen-enhanced decohesion (HEDE);
  - Hydrogen-enhanced local plasticity (HELP)
  - Adsorption-induced dislocation emission (AIDE).
- Weld metal hydrogen cracking contributing factors, including:
  - Sources of hydrogen;
  - Weld metal diffusible hydrogen - definition and testing;
  - Hydrogen ingress during welding;
  - Solubility of hydrogen during welding;
  - Hydrogen trapping;
  - Weld metal composition and weld microstructure;
  - Weld metal hardness;
  - Welding residual stress.

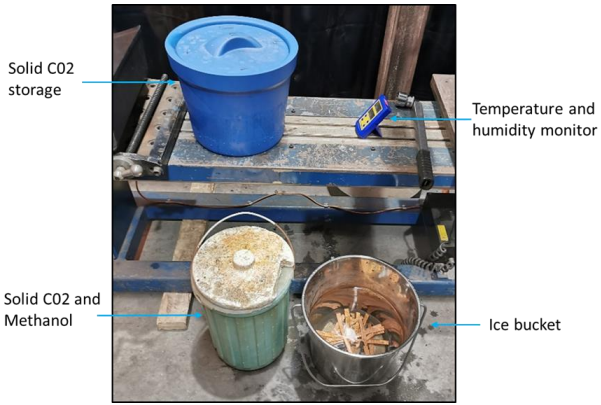
Establishing a Cracking Condition

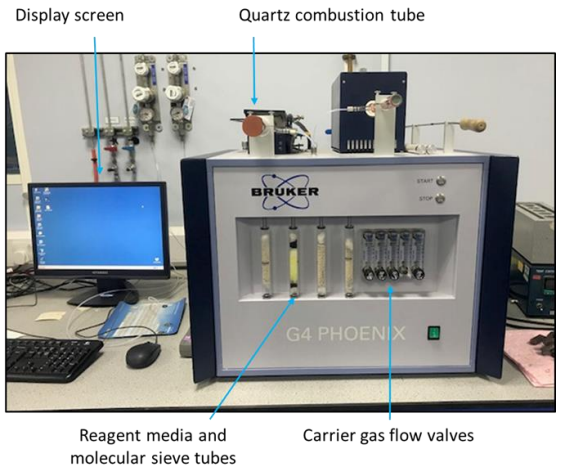
Empirical research was carried out to establish a condition for producing welds with suitably high concentrations of diffusible hydrogen:

- U-Groove testing - BS EN ISO 17642-2 self-restraint test for weld metal cracking (macro sections);
- 50mm thick QT Grade BS EN 10025-6 S690QL;
- Hydrogen charged welding consumable BS EN ISO 18276-A: T 69 4 Z P M 2 H5;
- Diffusible weld metal hydrogen content established - ISO 3690.

Diffusible Hydrogen Measurement







1. Heated to 400˚C using infrared radiation (IR).
2. Liberated hydrogen transported in a stream of nitrogen gas through a Schütze reagent and molecular sieve to remove contamination.
3. The gas moves through the TCD where the change in thermal conductivity of the stream gas is compared to the reference pure carrier gas (nitrogen) by pair of thermistors in a Wheatstone Bridge.
4. Presented as H_D ml per 100g deposited weld metal.

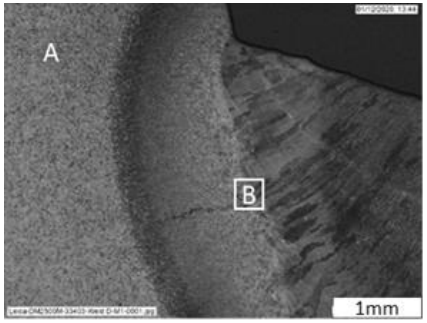
Determining a Cracking Condition

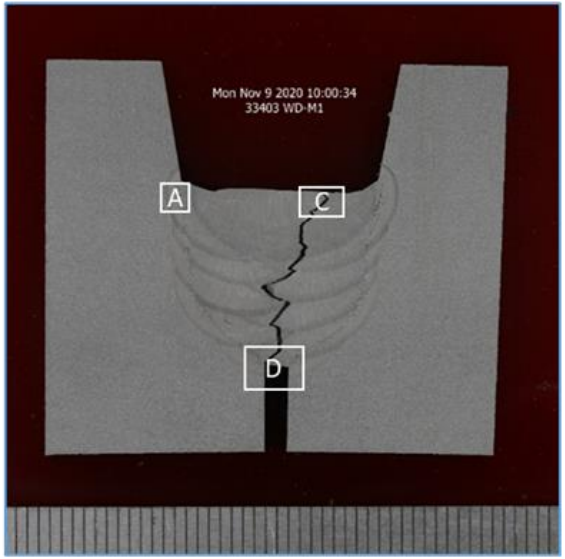
Stored at correct humidity and temperature in sealed packaging

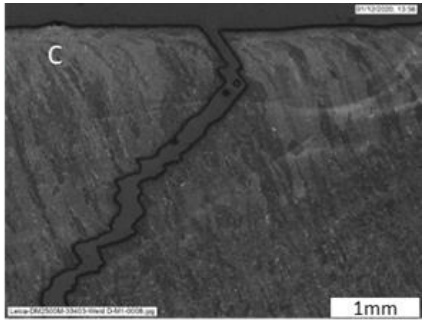
Specimen Identification			H_D ml per 100g deposited weld				Cracked/ Location	
Wire Storage Condition	Weld Type	Weld ID	Result 1	Result 2	Result 3	Average	WM	HAZ
A	U-Groove	UG-A	11.00	6.90	7.69	8.53	x	
	Butt-Weld	BW-A	5.16	5.25	5.49	5.30		
B	U-Groove	UG-B	7.24	6.58	6.41	6.74	x	
	Butt-Weld	BW-B	7.16	8.31	7.50	7.66		
C	U-Groove	UG-C	10.45	9.78	11.24	10.49		x
	Butt-Weld	BW-C	5.42	5.65	6.19	5.75		
D	U-Groove	UG-D	22.76	20.88	21.86	21.83	x	x
	Butt-Weld	BW-D	8.98	8.97	12.46	10.14		
E	U-Groove	UG-E	23.53	18.72	18.44	20.23	x	
	NA	NA	NA	NA	NA	NA	NA	NA

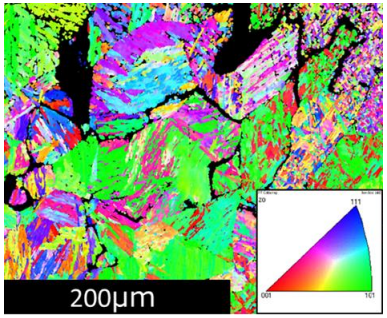
Stored outside in October.

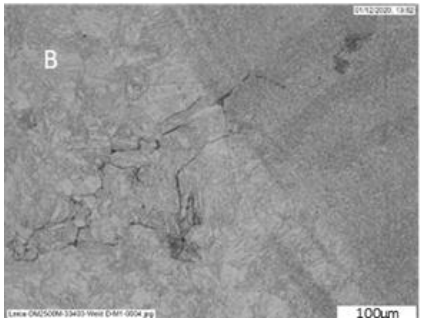
Specimen UG-D (21ml per 100g dwm)

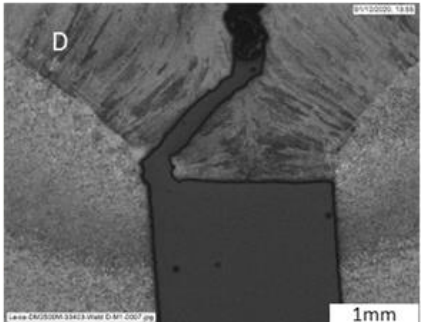




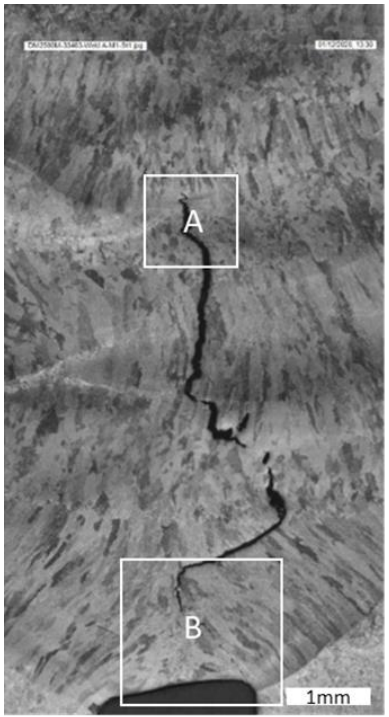


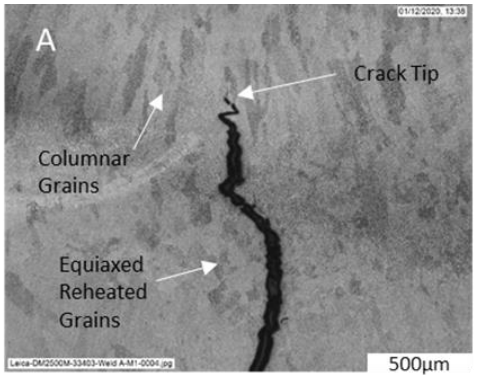


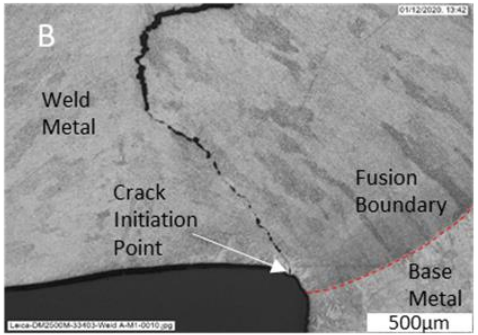


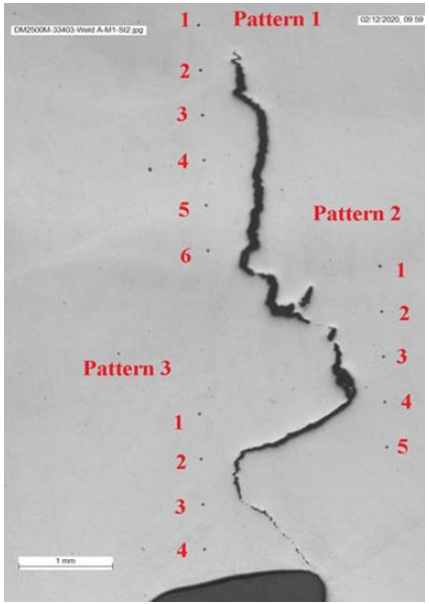


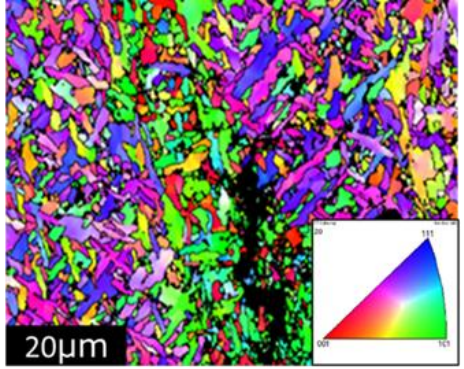
Specimen UG-A (8ml per 100g dwm)











Indent No.	Ocular 1	Ocular 2	HV
1	*24.7*	*25.6*	**293**
2	*25.8*	*26.4*	**272**
3	*26.0*	*26.4*	**270**
4	*25.4*	*25.0*	**292**
5	*25.8*	*25.0*	**287**
6	*26.2*	*26.0*	**272**
1	*25.4*	*26.9*	**271**
2	*25.4*	*25.0*	**292**
3	*24.3*	*23.9*	**319**
4	*25.2*	*23.9*	**308**
5	*25.2*	*24.3*	**303**
1	*25.0*	*25.6*	**290**
2	*25.2*	*25.4*	**290**
3	*24.7*	*24.1*	**311**
4	*24.1*	*24.3*	**317**

Observations….

1. Hydrogen charging using poor storage conditions is unlikely to yield repeatable concentration of weld metal diffusible hydrogen.

2. Relatively low levels of hydrogen can result in HACC if sufficient restraint/residual stress is present.

3. Vickers Hardness much below the understood safe working limit of 450HV (NHT) and 380HV (HT) may still result in WM HACC.

4. HAZ cracking appears to be microstructurally orientated and intergranular following the prior austenite grain boundaries.

5. WM cracking appears to be stress driven.

What's Next....

- Establish a repeatable method for producing welds with suitably high concentrations of diffusible hydrogen. Options currently being considered are:
  a. Doping the welding shielding gas with small additions hydrogen of gas.
  b. Conditioning the wire in an environmental cabinet with controllable temperature and humidity.

- Effect of Procedural Controls on Weld Metal HACC Condition:
  Full Factorial DoE - Trials to include preheat, heat input and hydrogen release treatment to understand the effect of procedural controls on the cracking condition.

- Crack or No-Crack Boundary:
  Produce models/nomograms to identify the required mitigation for the avoidance off weld metal HACC.

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