Computational Weld Mechanics of Hot Crack Nucleation in Nickel-Based Welds

Mahyar Asadi
Hot Cracking Driving Force

- Hot cracking can occur with all metals, in the fusion zone, and during welding.
- Eliminating the risk hot cracking is argued to be an impossible task, but understanding the causes of hot cracking should clarify the options available to reduce the risk of hot cracking.
- This was driven by the increasing demand from the energy, aerospace, and many other industries, and encouraged us developing CWM application for prediction of hot cracking.
Focus of This Work

- DDC in Heat Affected Zone
- LC in Partially Melted Zone
- SC in Fusion Zone
Mechanical vs. Metallurgical Approach

- Majority of research on hot cracking is based on metallurgical approaches analyzing local evolution of material and structures that help/prevent hot cracking.
- Mechanical approach quantifies material resistance to hot cracking under different stress, strain, and temperature.
- Mechanical approach developed in 1950’s by Prokhorov but still a limited research has been done on this approach.
- The main drawback is that the mechanical approach and measurement is not localized, in contrast to the actual localized nucleation of hot cracking as a direct result of evolution of state from the immediate neighbourhood.

The key is to develop a localized mechanical approach that interacts with neighboring zones
MISO Technique

Measuring the localized material resistance to hot cracking

In 1980s, Matsuda developed Means of In-Situ Observation (MISO) Technique for measuring the localized resistance.
Material Ressistance to SC & DDC

Strain to Nucleation

Solidification Cracking

Ductility Dip Cracking

Decreasing Temperature

SCTR (°C)

DDTR (°C)

εTH

TLS

0.5 x TL

[the Ohio State University, 2008]

[MACE: Plasticity – Lab. UK, 2012]
Mechanical Criteria for SC & DDC

Inconel BTR [1300 - 1400] C

SC Criteria;
BTR + Tension + Strain Rate

DDC Criteria;
DDCTR + Miner’s rule

Accumulated damage reaches the threshold value at DDTR

\[ \sum_{i=1}^{n} \frac{\Delta \epsilon_f(T(\Delta t_i))}{\epsilon_f(T(\Delta t_i))} = \sum_{i=1}^{n} f_i(\Delta t_i) \]

Looking to the rate of strain and temperature at the same time for every node

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Computational Welding Mechanics

Assessing the risk of hot crack based on mechanical approach using 3D evolution of the stress-strain-temperature state

Demonstrating the capability of CWM as an effective design tool for predicting the risk of hot cracking in welded structures
Solidification Cracking Test

Experiment by Matsuda et al
Inconel 600 – FM 82
Size 300x50x2 mm
Voltage = 19.5 v, eff = 0.7
Speed = 2 mm/s
Current 35 amp

Variable: Cross head Speed / Rate
20, 2, 0.2, 0.1 mm/s

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Solidification Cracking Test
Solidification Cracking Test
Ductility Dip Cracking Test

Variable: Welding Speed
2 and 5 mm/s

Experiment by Chen et al
Inconel 600 – FM 82
Size 100x100x2 mm
Voltage = 10 v, eff=0.6
Speed = 2 & 5 mm/s
Current = 100 & 180 amp
Ductility Dip Cracking Test

2 mm/s

Thermal results and DDTR

5 mm/s
Ductility Dip Cracking Test

2 mm/s

5 mm/s

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Ductility Dip Cracking Test

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Example of Prevention of SC & DDC

Controlling the process parameters:
7 welding speeds, 4 traction forces

Faster speed
Higher load

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Conclusion and Remarks

A methodology to assess the risk of hot cracking based on CWM analysis was demonstrated and performed for experimental tests.

This methodology is developed based on localized mechanical approach using 3D evolution of the stress-strain-temperature state.

Assessing the risk of Solidification Cracking for the entire domain is facilitated by using a global post processor algorithm.

Assessing the risk of Ductility Dip Cracking is implemented by using result of constant temperature test together with Miner’s rules.

The capability of CWM is shown as an effective design tool for predicting the risk of hot cracking in welded structures.
Mahyar Asadi
masadi@uottawa.ca
masadi@enteknograte.com