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Permanent effect of a cryogenic spill on fracture properties of structural steels

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Outline

- Motivation
- Objective
- Materials
- Experimental
- Results
- Conclusion

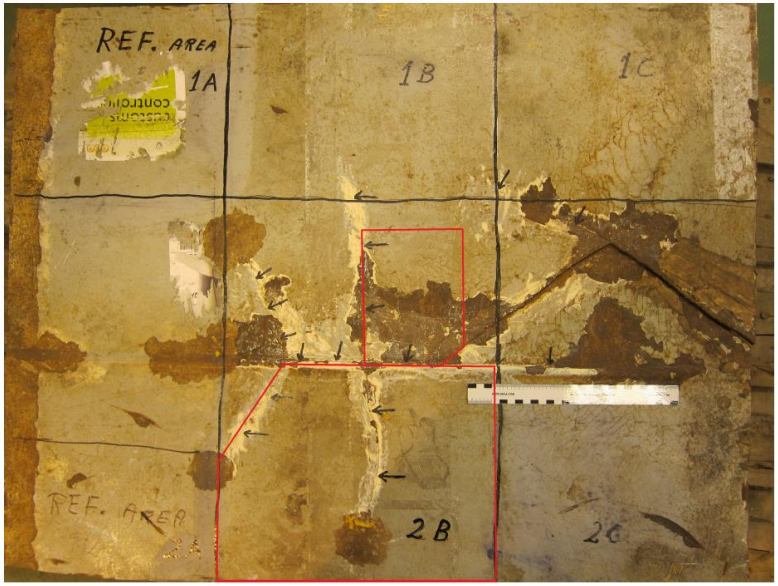
Motivation

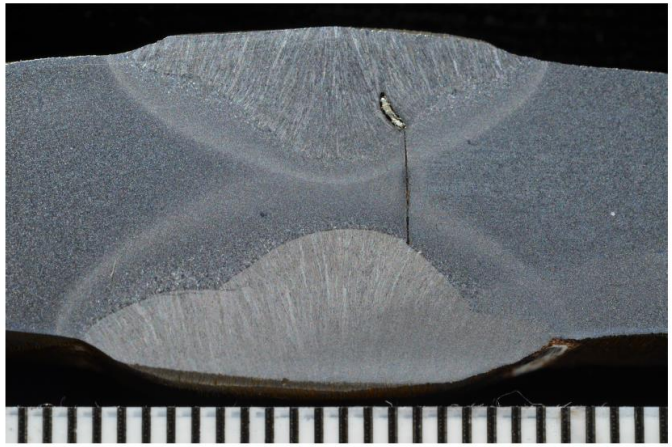
Failure due to cryogenic spill happens with a BANG

Carbon steel platform deck exposed to liquid nitrogen → failure → flaw in a weld

Standard procedure:

- Visual and NDT testing
- Remove damaged material
- Replace with new material





Objective

Is it sufficient to only remove damaged material?

or

does a cryogenic spill affect the fracture properties of structural steels permanently?

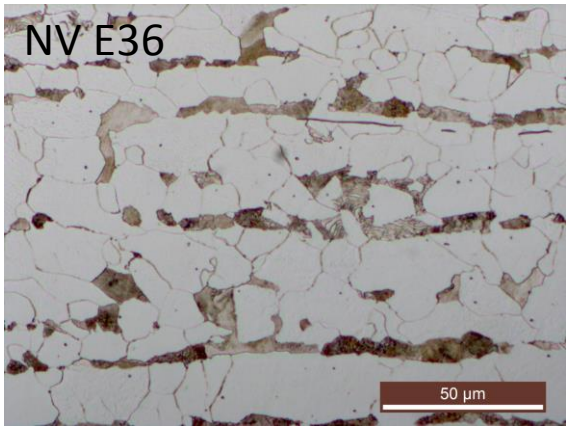
Materials

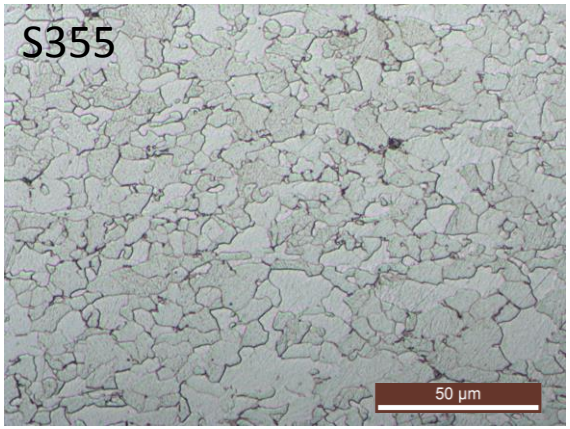
Two structural steels:
NV E36 ← platform material
DOMEX S355 MCD

	NV E36	S355
Yield [MPa]	355	377
UTS [MPa]	470	450
Elongation [%]	21	39

	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Al	Nb	V	Ti
NVE36*	0.20	0.10-0.55	1.70	0.030	0.030	0.20	0.08	0.40	0.35	min 0.02	0.02-0.05	0.05-0.10	0.007-0.05
S355**	0.069	0.01	0.62	0.009	0.003	0.03	0.00	0.03	0.01	0.046	0.023	0.00	0.00

* Specification
** Certificate





NV E36: perlitic steel
large grain size
elongated sulphides

DOMEX: Low carbon steel
ferritic microstructure
small grains
low in S and P
offshore applications

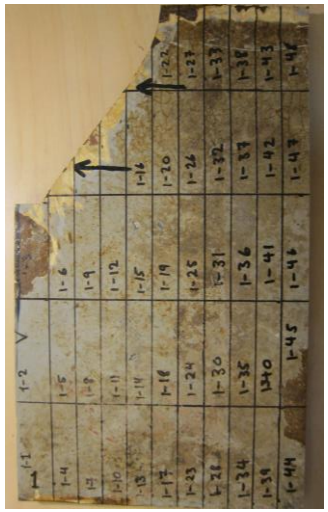
Experimental setup – platform materials

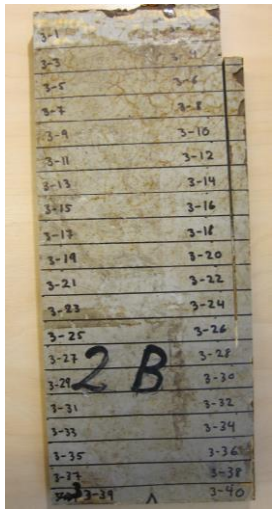
NV E36

«Exposed» and «non-exposed» areas

- Charpy V-notch impact testing
- Notch perpendicular and parallel to the rolling direction
- Temperature: 0°C (32°F)

- Fractography
- Cross section examination





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Experimental setup – simulated spill

Tensile testing in liquid nitrogen
Quasi-static: 1 mm/min
Reference samples tested at -196°C

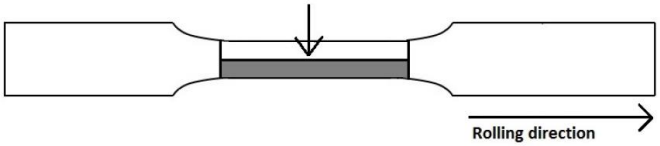
Pre-stress in elastic region for 10 min:
DOMEX S355: 1000 N, 4000 N and 6500 N
NV E36: 5000 N

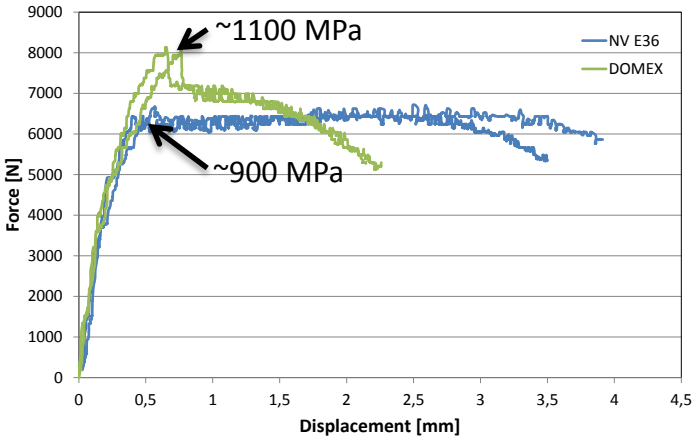
Tensile testing at room temperature

Metallographic investigation of cross sections of pre-stressed samples

Testing at -196°C

Material	Force [N]
NV E36	Ref
NV E36	5000
S355	Ref
S355	1000
S355	4000
S355	6500





Results – Charpy impact testing

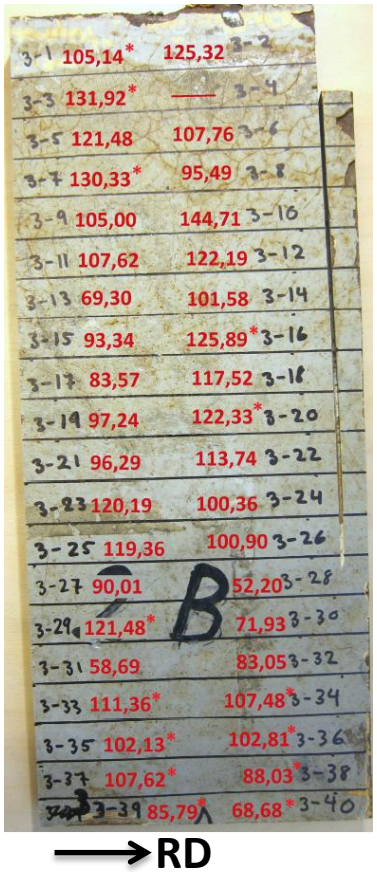
Average: 38.68 J

Min: 24.47 J

Max: 76.49 J (instantaneous stress relief)

Required: ~ 64 J at 0°C

Too low



Average: 102.83 J

Min: 52.20 J

Max: 144.71 J

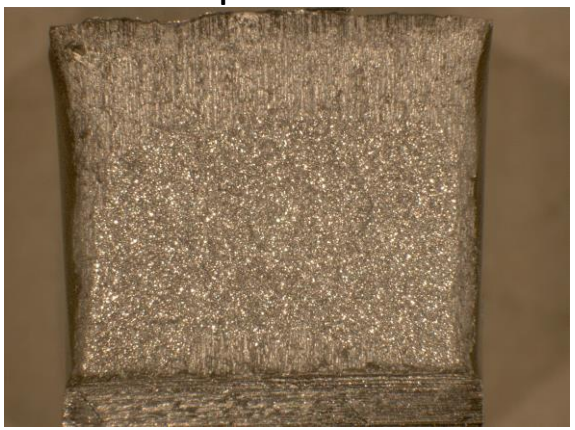
Required: ~ 74 J at 0°C

A few values >52 J acceptable

But still lower than expected

Platform material - microstructure

Sample 1-30



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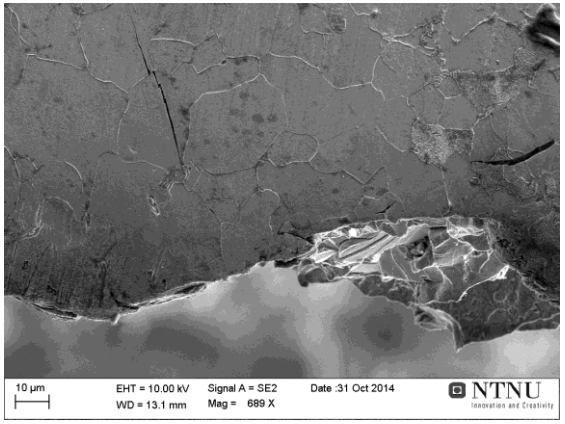


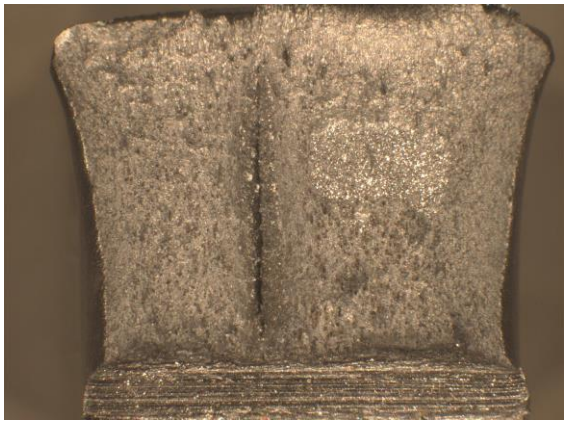
Sample 1-30:

- Brittle behavior
- Cracks only observed near the fracture surface

Sample 3-34:

- Mainly ductile
- Macro crack
- Shear behavior
- Small cracks near the fracture surface

Sample 3-34



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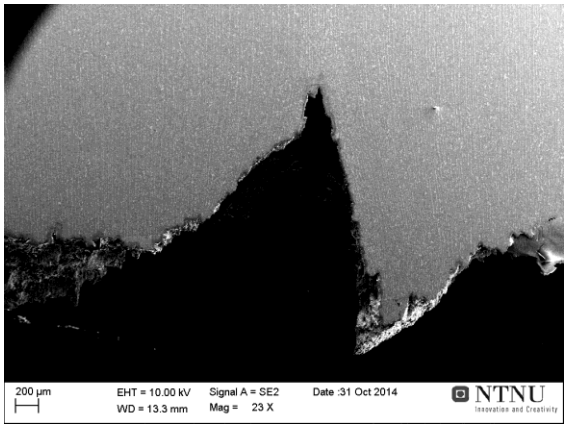
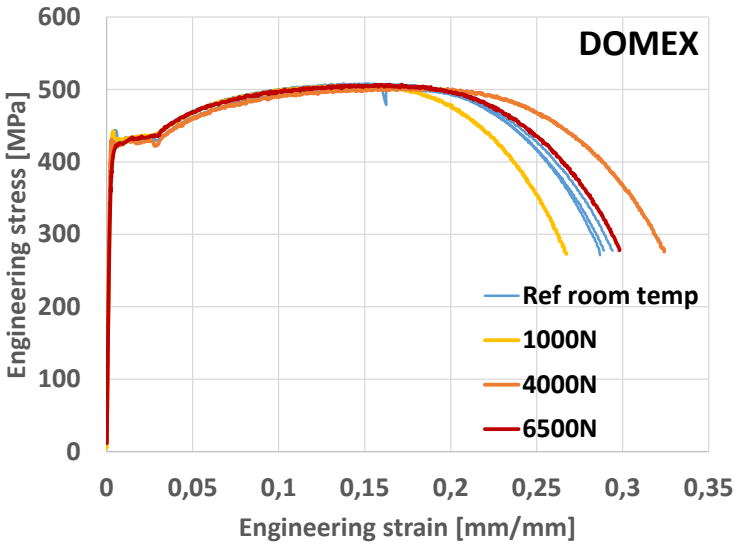
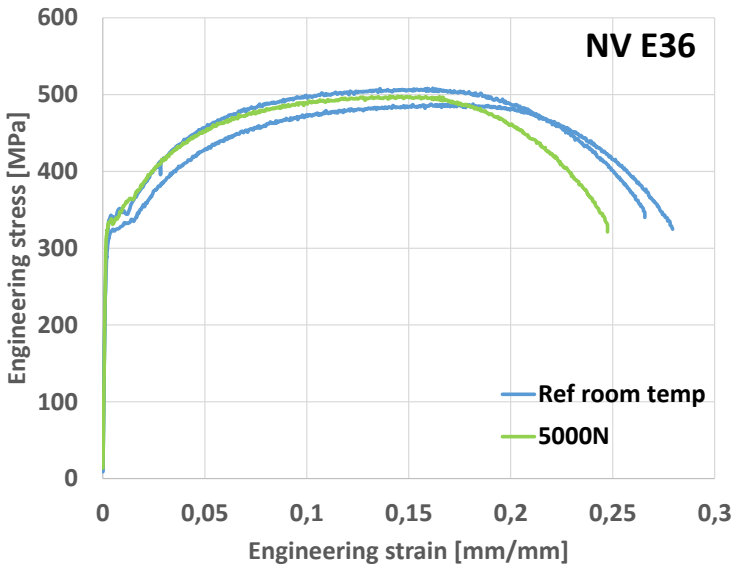


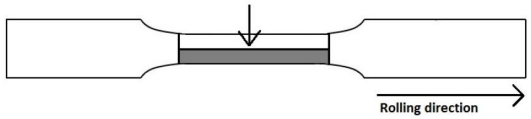
Simulated spill – tensile testing

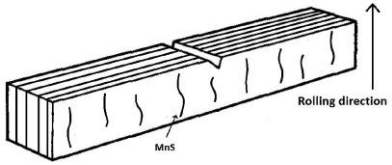
- No particular difference observed when tested at room temperature
- Upper yield point gradually decreases with increasing pre-stress





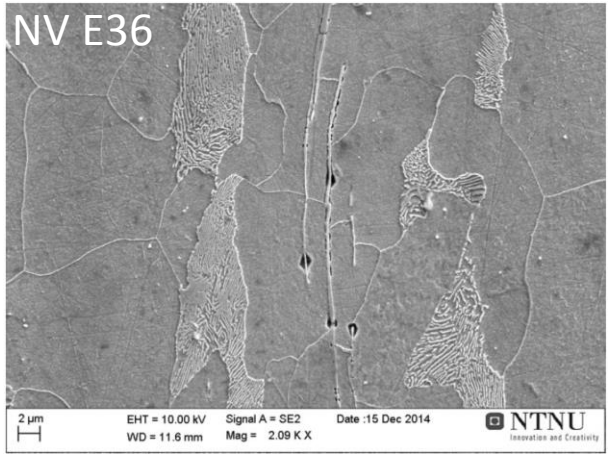
Simulated spill - microstructure

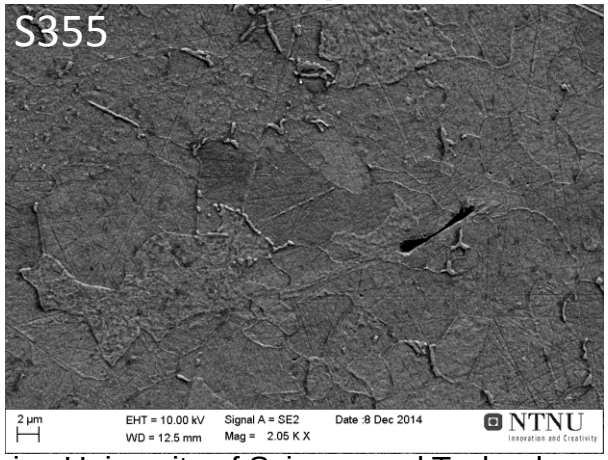


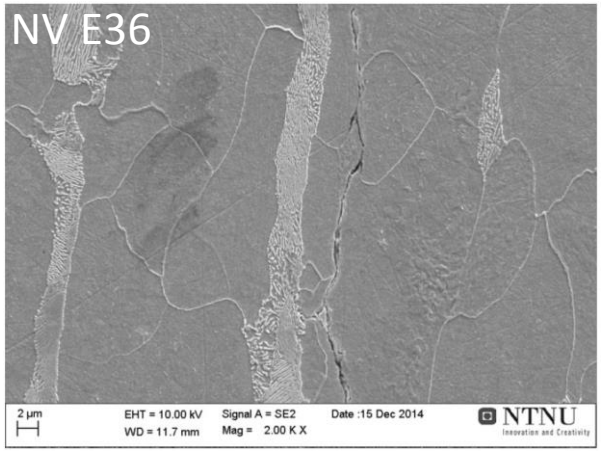


Two types of cracks observed in pre-stressed material:

- DOMEX S355 – micro cracks
- NV E36 – sulphide related cracks (difference in thermal expansion coefficient)







Conclusion

- Critical reduction in Charpy energy (NV E36)
  - Notch parallel to the rolling direction
  - Cracks related to sulphides (difference in thermal expansion coefficient)
- Simulated spill
  - Tensile testing at -196°C:
    - Increase in yield strength
    - OK ductility
    - no work-hardening → Lüders region → fracture
  - Room temperature tensile testing:
    - Decrease in upper yield point with increasing pre-stress
    - No particular difference when tested in the rolling direction

A cryogenic spill may cause permanent damage

Further work

- Charpy V-notch testing of DOMEX S355 MCD
- Tensile testing perpendicular to the rolling direction
- Bi-axial stress at -196 °C more accurate than uni-axial stress

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Thank you for your attention