Dissimilar Metal Welds (DMW) in German LWR's

Design Types, Disbonding, NDT

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Scope

Flaws/Cracks in Dissimilar Metal Welds (DMW)

1. Interfacial Flaws/Cracks in DMWs’ ("Disbonding")
   - DMW-types / Influence Factors on Disbonding /
     Appropriate NDT-methods
   - Results and Conclusions of Recent German
     Investigations and NDT-Examinations

2. Transverse Cracks in NPP - Virgil C. Summer)

3. Control Rod Drive Mechanism (CRDM) Incidents
   (e.g. Oconee Nuclear Station)
1. Disbonding at Interface Buttering / Ferritic Steel

- Location of cracks in a German NPP detected by ISI

- Hot cracks detected by Penetration Testing (PT) after grinding

- Disbonding: crack detected by Ultrasonic testing (UT) during ISI

  - Crack depth: 16 mm (~0.6 in.)
  - Crack length: 200 mm (~8 in.)

- Buttering: austenitic

- 22 NiMoCr 37 ~ ASTM 508 Cl.2

- SS (1.4550)
Welding Process Inspections Performed

- Inspection of interface (UT* or RT*) after buttering:
  - bonding o.k.
  - Crack follows from joint welding

- Final fabrication inspection of DMW - disbonding not detected
  - PT*: overwelding of the interface
  - RT: interface not in the focus of NDT

* PT: Penetration Testing
  RT: Radiographic Testing
  UT: Ultrasonic Testing
Influences on Potential Disbonding Occurrence

- **Austenitic filler metal:**
  - Hardness increase due to chromium carbide precipitation
  - Intense carbon diffusion from ferritic to austenitic side during past weld heat treatment of buttering
  - High residual stresses during the welding process

- **Inconel filler metal:**
  - Disbonding not to be expected due to negligible chrome-carbide precipitation at the interface;
  - Very low carbon diffusion due to high nickel content

⇒ disbonding possible

⇒ o.k., no disbonding
Austenitic buttering: Increased hardness at interface due to carbide precipitation and carbon diffusion after welding and heat treatment.

Buttering: austenitic (1.4550)
1. Layer: high alloyed electrode

Cladding type 1.4550

Buttering: austenitic (1.4550)

Martensitic and carbide zone

Fusion line

C - Diffusion
Disbonding at Interface...

**Austenitic buttering: residual stresses**

Disbonding of buttering due to residual tensile stresses (shrinkage) during manufacturing of joint weld.

Increasing shrinkage stresses
Conclusion: Root cause of crack
⇒ singular fabrication defect (not generic),
no crack growth during plant operation

Required Remedial Actions in German NPPs:

Review weld fabrication-NDT and ISI-NDT results (UT and/or RT)
of DMW with buttering:
extent/sensitivity of UT/RT records cover

- weld-inside/-outside /-volume sufficiently ⇒ No action req.
- weld-inside/-outside/(no volume) sufficiently ⇒ Actions in later outages

• no sufficient extent/sensitivity of UT/RT records ⇒ Immediate action in next outage

RT: Radiographic Testing; UT: Ultrasonic Testing
DMW with buttering in German NPPs:
Location in Reactor Coolant Pressure Boundary (RCPB)

- German BWR: - joints of stainless steel SS-lines to ferritic RPV
  - safe ends of austenitic valves

- German PWR: - joints of the ferritic MCL to connected lines

Dimensions:

pipe diameter $100 \leq OD \leq 450$ mm ($\sim 4 - 16$ in.)
wall thickness $15 \leq t \leq 55$ mm ($\sim 1/2 - 2$ in.)
Different Design of Dissimilar Welds **with Buttering** in German NPPs

\[ 15 \text{ mm} \leq t \leq 55 \text{ mm} \]
Dissimilar Welds with Buttering - Welding Materials

**German BWR:**

<table>
<thead>
<tr>
<th>Old Design</th>
<th>New Design</th>
</tr>
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<tbody>
<tr>
<td>root:</td>
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**German PWR:**

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* in some cases root: austenitic
  filler: inconel 82

Most DMW are shop welded ⇒ good fabrication conditions
Dissimilar Welds without Buttering: Location in Pressure Retaining Boundary of German NPPs

- German PWR: RPV closure head
  1. control rod drive mechanism
  2. pressure housing

**Dimensions**

- pipe diameter $65 \leq \text{OD} \leq 140 \text{ mm} \ (\sim 2.5 - 5.5 \text{ in.})$
- wall thickness $5.4 \leq t \leq 23.5 \text{ mm} \ (\sim 1/4 - 1 \text{ in.})$
Dissimilar Metal Welds without Buttering: Different Design Types in German NPPs

Pressure housing

5.4 mm ≤ t ≤ 13.5 mm

CRDM-flange

t ≈ 23.5 mm
Dissimilar welds **without** Buttering - Welding Materials

German PWR: closure head

1. Control rod drive mechanism (CRDM)-flange
   &
2. Pressure housing

   root: austenitic
   filler metal: inconel 182

DMW are shop welded $\implies$ good fabrication conditions
NDT of DMW using Ultrasonic Testing (UT)

PWR + BWR: DMW are scanned from pipe outside OD

Examination of Disbonding

**Recording limit**
inner and outer surface: 2 mm deep notch (~ 0.1 in.),
volume (wall thickness > 20 mm): CRR* 5

**Inspection technique**
phased array probe,
Long/Long/Trans (LLT-) probe,
70 degree dual longitudinal transducer (70 SEL)

* (circular reference reflector)
Phased Array-technique (45 SET 1.5)

- Examination from austenitic and ferritic side
- Different angles of incidence used to scan the ID, OD and volume
  Different focus path lengths are possible
Compact Long-Long-Trans (LLT)-Technique
(substitute for tandem technique)

- Examination from ferritic side

- Depending on wall thickness different angles of incidence are necessary to detect disbonding in weld volume
NDT of DMW using Radiographic Testing (RT)

- X-ray to be used; double wall radiographic required ⇒ max. wall thickness 25 mm
- Required angle at fusion line < 5-6° to detect small cracks
Performed Extent of DMW-NDE in German NPPs

- **PWR**
  - “disbonding-NDT” performed in 10 of 13 German PWRs’
  - approximately 10 - 15 DMWs’ with buttering (austenitic or inconel) per plant inspected (RCPB)

- **BWR**
  - “disbonding-NDT” performed in 5 out of 6 German BWRs’
  - approximately 6 DMWs’ with buttering inspected (RCPB)

**Result:**
No disbonding detected at any DMW with buttering!

**Dose rate:** ~ 30-40 mSv per plant
**costs:** ~ 450.000 DEM (~ 225 000 US $) per NPP
⇒ Total costs (estim.): 4 million US $
2. Transverse Crack in the Buttering (V. C. Summer)

Design of the DMW

Repair of the weld

Crack location
2. Examination of Transverse Defects: Extent and Results of NDE in E.ON NPPs

- According to German KTA code requirements, examination of DMW’s for transverse defects not requested at present.

- GRS-Bulletin ⇒ actions required in next outages

- UT-examination of 8 DMWs (inconel filler) performed this year

Result:
No crack indications in all examined DMWs
3. Control Rod Drive Mechanism (CRDM) Incident (Oconee Nuclear Station)

**Design**
- German design different to French or US design
- CRDM are not directly welded to the RPV closure head, screwed connection with seal weld

**NDT**
- Examination of seal welds: visual testing (video inspection)
- Examination of DMW at CRDM flange and pressure housing
  - eddy current testing

**NDE-Results in German NPP** ⇒ o. k.
Design of the CDRM