Development of Welding and Hardfacing Technology: challenges for ASTRID project

Sophie Dubiez Le Goff & Anne-Françoise Bonnot

and T. Marlaud (AREVA), D. Pierron (AREVA), L. Forest (CEA), J.-P. Mathieu (EDF), M. Blat-Yrieix (EDF), M. Blanc (CEA)

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OUTLINE

1. **Welding Studies**
   1. **Context and general points**
   2. **Ongoing investigations for ASTRID**
   3. **Focus on : Welding of 316L(N) - 19.12.2 SMAW**
2. **Hardfacing challenges for in-sodium application**
   1. **Context and general points**
   2. **Processes and materials**
   3. **Samples procurements**
   4. **Evaluation program**

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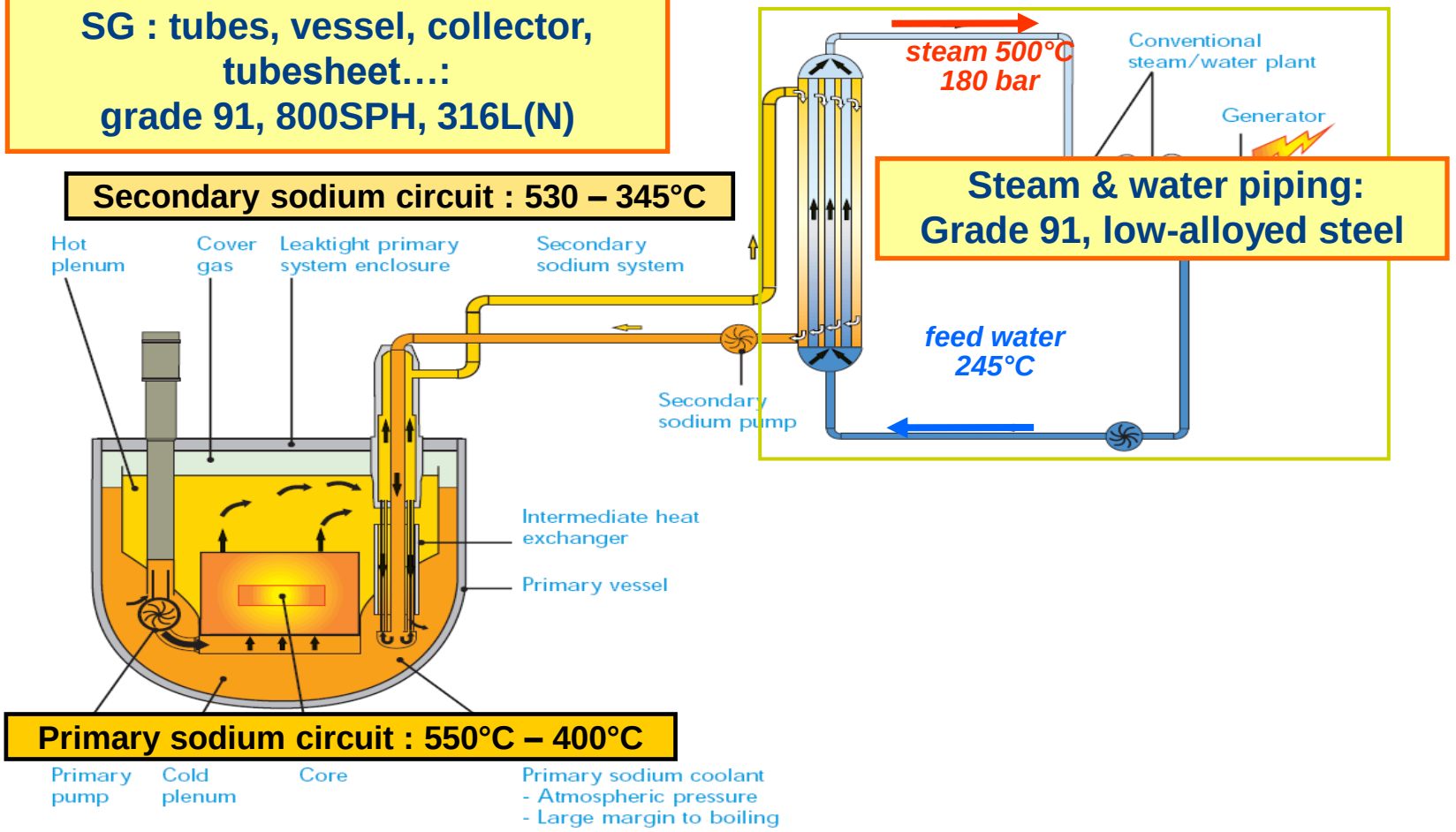
Welding studies
Context and general points

Water/Steam circuit or Gas system

SG : tubes, vessel, collector, tubesheet…:
grade 91, 800SPH, 316L(N)



316 L(N)
- Primary vessel, inner vessel, core support structure, secondary piping…

Welding studies
Context and general points

- **316L(N), grade 91, 800SPH, 16MND5, A48…**
- **Compromises between :**
  - Good ductility properties (toughness, impact, elongation…)
  - Room/high temperature resistance (creep, strength..)
  - Metallurgical & process weldability

  ➡ **Development of specific welding filler materials used in creep conditions**

Proposed approach for welding developments for candidates materials

- **Welding developments on reference processes (SMAW, GTAW)**
  - Flat position (test plate, joints), welding in position…

  ➡ **Representatives joints for R&D : long term creep…**
- **Alternative processes : more productive, residual stress reduction…**
- **Other : weld repairs, specific developments (tube-to-tubesheet…)**
- **Heterogeneous welds : 316L(N)/800SPH, 316L(N)/grade 91, 800SPH/grade 91, 800SPH/Low alloyed steel …**

Ongoing investigations for ASTRID welding developments

- **316L(N) : Development of specific welding filler materials**
  - **SMAW : validate & master again experience on 19.12.2 grade**
  - **Automatic GTAW : development of a solid wire**
  - **Identification of potential alternatives processes : EBW, GMAW NG, …**
- **Grade 91 : Development of specific welding filler materials**
  - **SMAW : development of electrode**
  - **Automatic GTAW NG : development of a solid wire**
- **800SPH : choice of filler metal for SG tubes butt joints & dissimilar joint 800SPH/grade 91**

Welding of 316L(N) - 19.12.2 SMAW

316L(N) : solidificates in a complete austenitic mode

- **Austeno-ferritic 19Cr12Ni2Mo Weld metal (19.12.2)**
- **Feedback from RAPSODIE, PHENIX and SPX : >130 lots of electrodes**

Large long term R&D investigation + construction feedback

➡ Lead to the current deposited metal RS2711.1 of RCC-MRx

19.12.2 grade = adjusted composition:

- Control of ferrite : good thermal aging at 550°C / avoid hot cracking in all welding position
- Chemical comp. close to BM : limit dilution effects
- Control of impurities (versus hot cracking, properties degradation…)
- A control of elements favouring sigma phase
- An optimised composition towards high temperature properties & sensitivation to intergranular corrosion

Main 19.12.2 requirements on test plate: (check that the mechanical properties of the weldment belong to the dispersion band)

- Chemical of deposited metal
- Ferrite (3-7%)
- KV impact (As weld & after accelerate aging 100h at 750°C)
- Tensile properties at RT , at 550°C
- Creep at 550°C
- Accelerated intergranular corrosion test
- Groove cracking test

First objective: to master again the experience on 19.12.2 grade : testing 19.12.2 electrodes not already marketed by European consumable suppliers

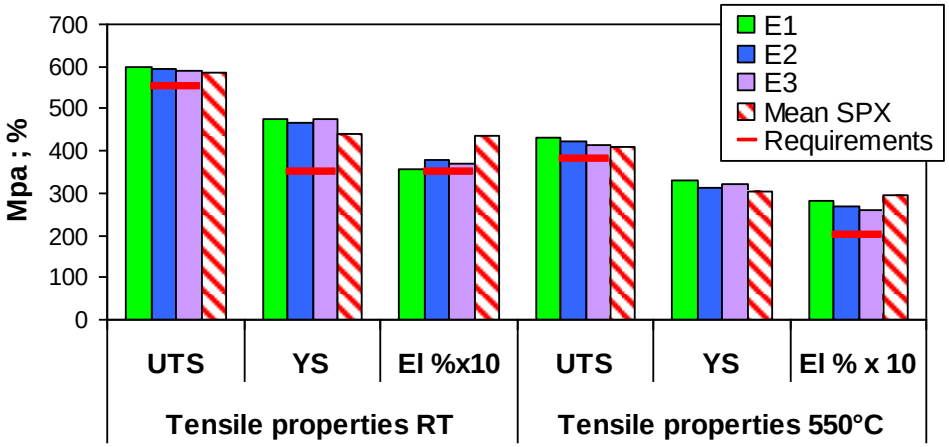
Welding of 316L(N) - 19.12.2 SMAW

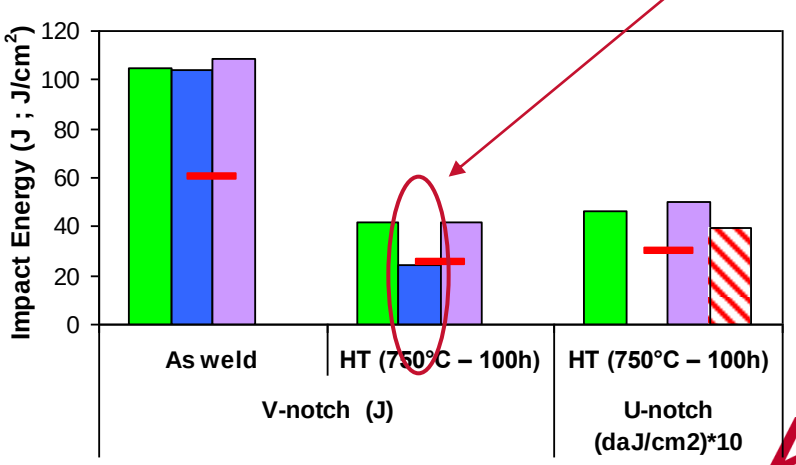
Characterization of three electrodes: weld metal deposited in flat position

- **Properties of deposited metal are close to SPX mean values**
- **E2 : Toughness of after aging is consistent with composition**
- **The accelerated creep test at 550°C, groove cracking test, accelerated int. Corrosion test : valid**

Chemical composition of main elements of deposited metal

Chemical composition (wt. %)		C	Ni	Cr	Mo
RCC-MRx specifications	min	0.045	11	18	1.9
	max	0.055	12	19	2.2
Mean SPX (test plate & qualification)		0.051	11.53	18.52	1.99
E1		0.056	11.89	18.53	2.09
E2		0.051	11.53	18.19	2.26
E3		0.048	11.76	18.54	1.89
Base Metal 316L(N)		0.027	12.14	17.58	2.54



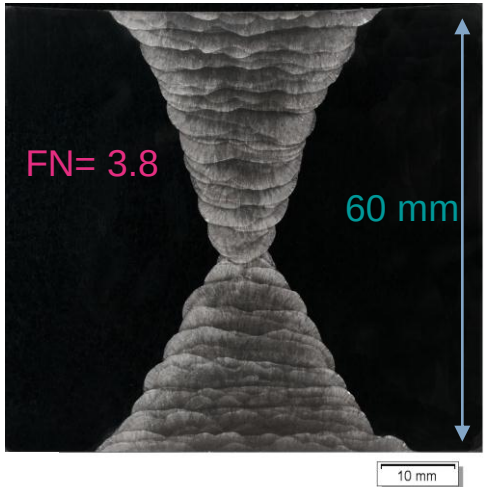


Welding of 316L(N) - 19.12.2 SMAW
Welding in position : characterization of electrode E3

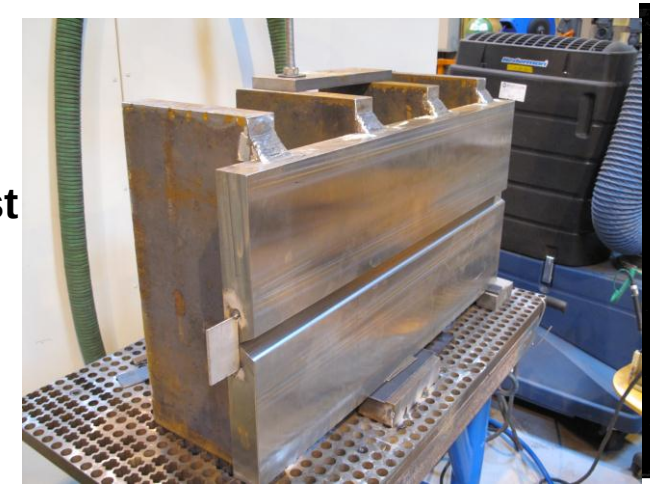
- **Cracking test in vertical upwards progression (PF/3F) position**
  - "sweep" passes from one edge of the groove to the other, high energy

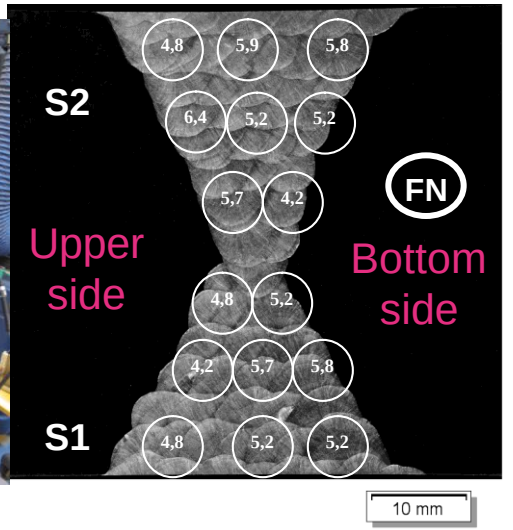
    Not representative of industrial welding conditions, but severe for hot cracking
  - Results : Absence of crack & homogeneity defect.

    E3 is not sensitive to hot cracking



- **horizontal (PC/2G) position:**
  - **Chemical composition, ferrite, mechanical properties, bending test, accelerate intergranular test are conform to requirements (RS2711.1)**
  - **Longitudinal and transversal properties tensile properties are ok (rupture in base metal)**





Welding of 316L(N) - 19.12.2 SMAW
Correlation KCU/KCV

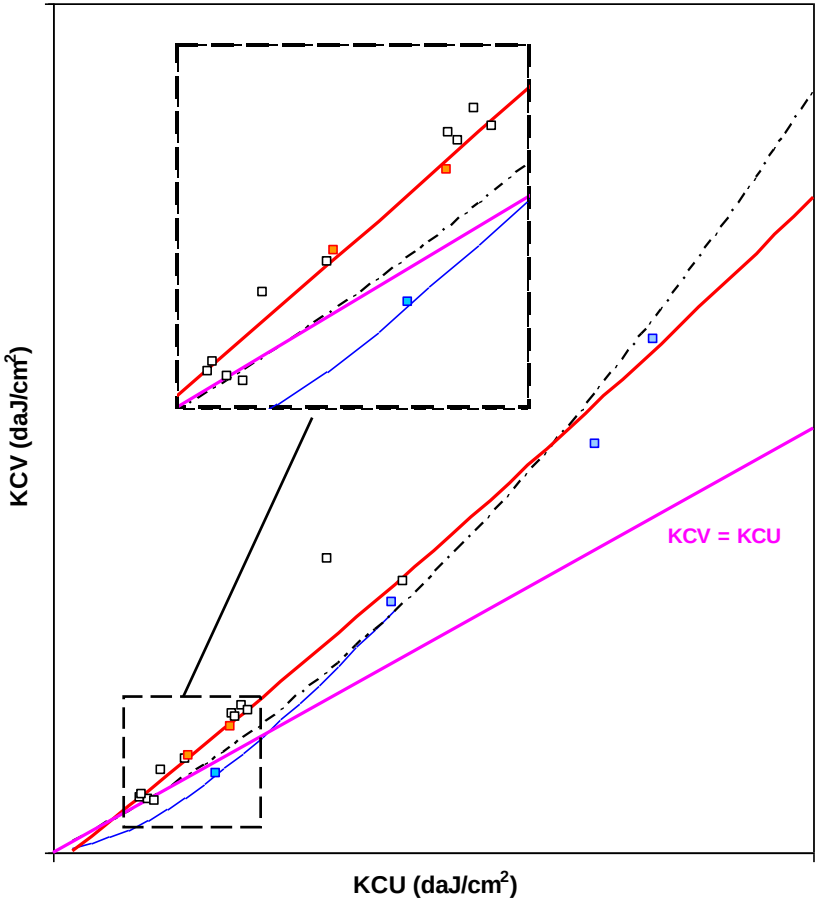
- **A large long-term R&D investigation show that on this grade :**

  KCU ≥ 3daJ/cm² after an accelerated aging at 750°C 100h, ensure KCU ~ 3daJ/cm² after 100 000 h at 550°C.

- **Due to Standardization evolutions, the KCU requirements in as weld and after accelerated aging conditions have been replaced by KV requirements in RCC-MRx code.**

  Need of a correlation between KCV & KCU

- **Correlation between KCV & KCU is non linear**



Welding of 316L(N) - 19.12.2 SMAW Conclusions

- **2 tested electrodes of 2 European suppliers give satisfactory results:**
  - **In flat position & horizontal (PC/2G) position**
  - **No hot cracking susceptibility : groove cracking test, cracking test in vertical upwards progression (PF/3F) position**
- **Next steps :**
  - **Work on "usability" of electrodes :**

    Be able to ensure an acceptable "usability" through:

    - added specifications on electrode coating (like Basicity Index) and/or a technological test (Slag Detachability...)
    - and defined a window of welding parameters

  - **Reproducibility between lots of electrodes of a same suppliers**
  - **R&D : Complete long-term characterizations (aging, creep…) of welded joints**

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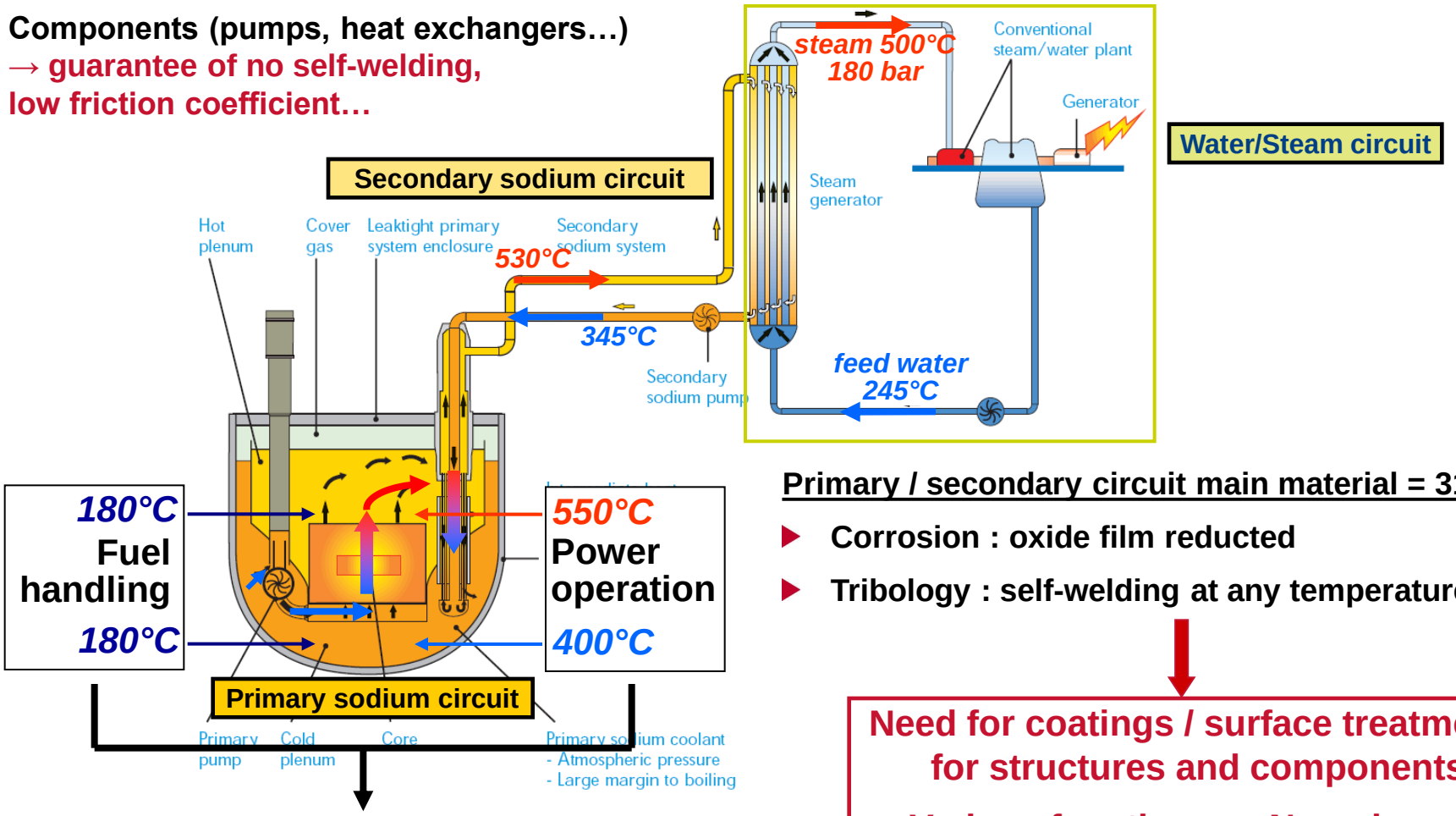
Hardfacing for in-sodium application
Context and general points

Components (pumps, heat exchangers…)
→ guarantee of no self-welding,
low friction coefficient…



Large temperature variation
Thermal dilatation → relative motion of structures

Primary / secondary circuit main material = 316L(N):

- **Corrosion : oxide film reducted**
- **Tribology : self-welding at any temperature**

Need for coatings / surface treatments for structures and components

Various functions → No universal solution for contact and friction zones

Hardfacing for in-sodium application
Processes and materials

- **Surface treatments (ex: aluminization, nitruration…)**
- **"Thin" deposits (few µm to 100µm)**

} ***Subsequently added to the experimental program***

- **"Thick" deposits (100µm to ~2mm)**

Materials :

Co-base grades → *appropriate for in-sodium application but not under irradiation*
Fe-base, Cu-base grades → *not appropriate for in-sodium and 400°C applications*

Ni-base grades

Short-term / Industrally available options:

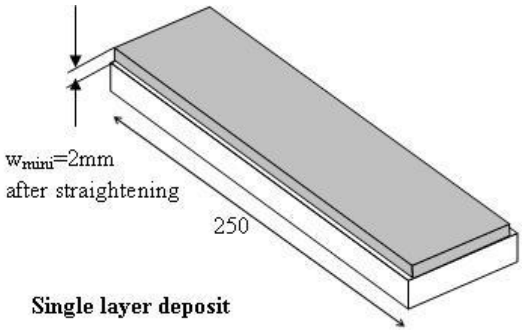
- **Type Colmonoy® 5** (NiCrBSi)
  Tribaloy® 700 (NiMoCrSi)
  Nucalloy® 453 (NiSi)
- **PTAW**

Medium-term / Substantial R&D effort:

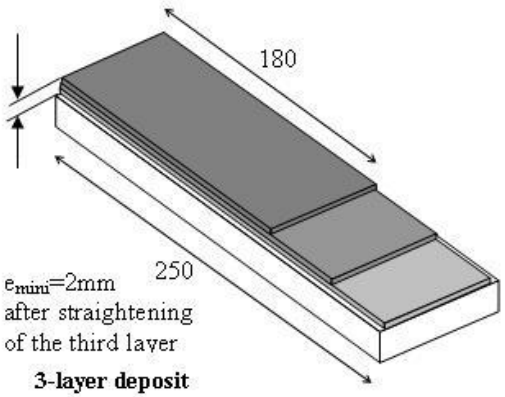
- **Composite hardfacing (nickel matrix + carbides charges)**
- **Thermal or Cold spraying**
  Laser welding

Hardfacing for in-sodium application
Samples procurements

- **For easier comparison between grades and providers:**
  - Common substrate (grade and geometry) = 316L(N) plate
  - Samples machined and grinded at the same workshop
  - Specific documentation effort during deposition :



Single layer deposit



3-layer deposit

Hardfacing performance

Filler material
- Alloy composition
- Form, geometry…

Raw hardfacing material sampling

Deposition process & parameters set
- Surface preparation and cleaning
- Pre- and post-heating
- Operator and machine
- Gases, amperage, speed, feeding, oscillations, layers order and directions…

+ temperature recording via thermocouple or pyrometer

Hardfacing for in-sodium applications Evaluation program

Reference during characterization: Stellite® 6

Phase 1: → **Discriminate promising solutions and eliminate least satisfactory ones**

- Detailled metallographic examination
- In-sodium corrosion → CORRONa
- In-sodium tribology → specific module in CORRONa²
  - tests solicitations // expected solicitations (speed, contact pressure…)

Phase 2: → **Get other major properties for promising alternatives**

- Mechanical properties (flexion, toughness, thermal and mechanical shock resistance…)
- Influence of welding parameters

+ development of out-of-sodium tribological device

medium- and long-term

Tests on samples ≠ **Real contact**

- Samples → scale and geometry effects
- Tests parameters → in particular for friction and wear tests
- Interaction between solicitations

Full-scale facility

Qualification program for a specific application (ASTRID priority = diagrid sleeves):
Evaluate the performance of planned alternative

ASTRID Welding and Hardfacing Technology : conclusion

- **Developments of Welding and Hardfacing Technology are undertaken through the evaluation of different solutions:**
  - **non commercial electrodes & experimental solid wires for 316L(N),**
  - **experimental & commercial solid wires for grade 91,**
  - **nickel-base hardfacings**

➡ **Define welding and hardfacing products specifications, finalize design of components….**

- **Further steps should integrate a qualification approach of products and processes, and should conduct industrial developments to solve manufacturing issues, as:**
  - **parts alignment issues for Narrow Gap welding,**
  - **the development of alternatives processes (EBW, GMAW…)**
  - **specific developments for made-to-measure tube-to-tubesheet welding,**
  - **chosen alternative hardfacing solutions for a given application,**
  - **dimensional tolerances and deformations for alternative hardfacing…**
- **In support: a large long-term R&D program on representative joints and hardfacing sollicitated under representative conditions**

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