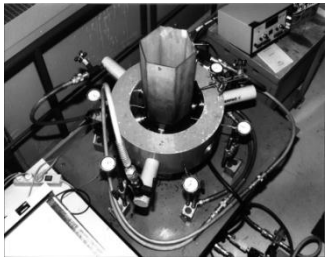
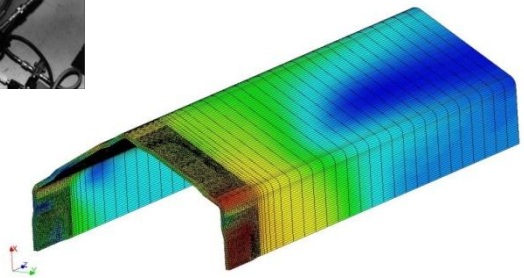
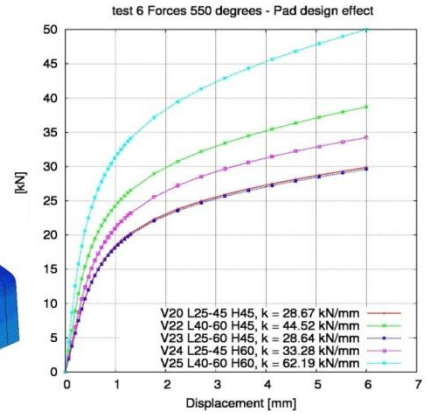
DE LA RECHERCHE À L'INDUSTRIE

Characterization, Simulation and Improvement of Spacer Pads Mechanical Behaviour for Sodium Fast Reactor Subassemblies







V. Blanc, X. Jeanningros, P. Lamagnère, T. Helfer, T. Beck

CEA Cadarache, DEN/DEC/SESC, F-13108 Saint-Paul-lez-Durance, France

www.cea.fr

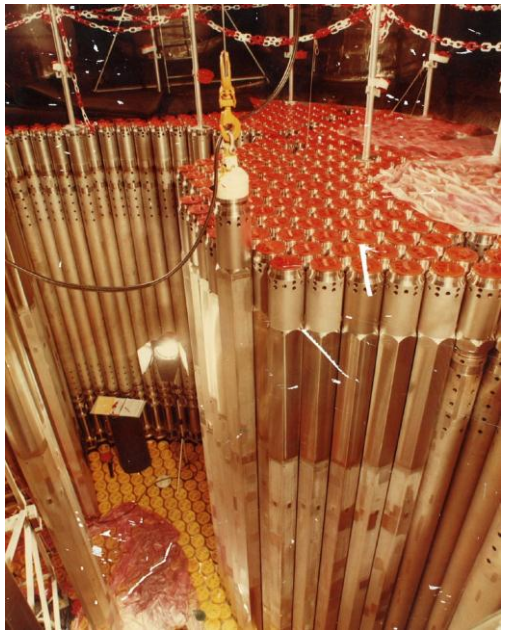
SMIRT 23 – Manchester - 10-14/08/2014

Outline

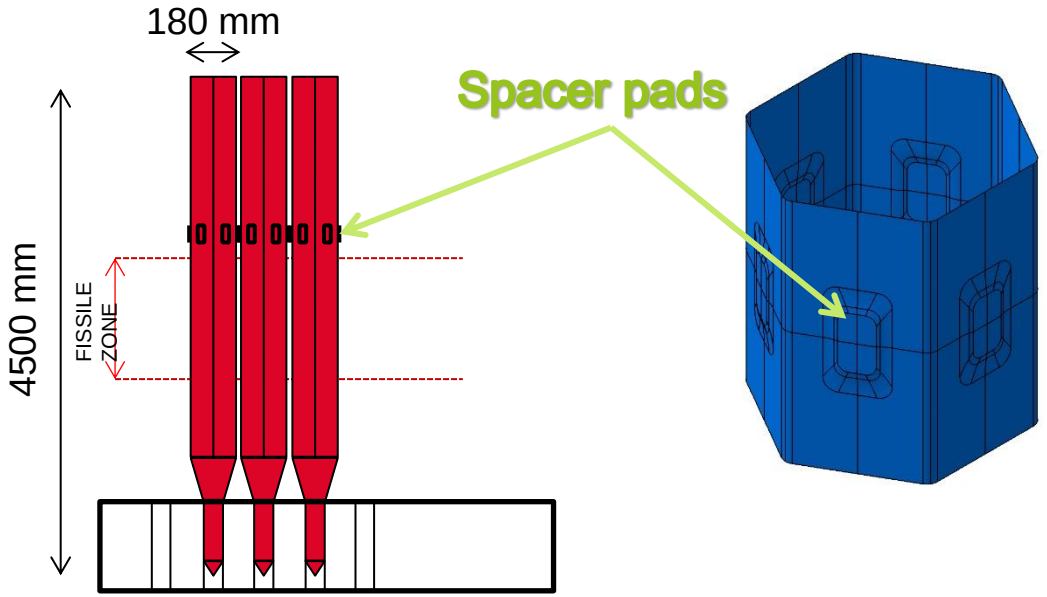
- Introduction
  - Spacer pads
  - Historical overview
  - Objectives
- Finite element model construction and validation
  - Geometry and stamping
  - Stamping simulation
  - Titan experiments and simulation
- Optimization process
  - Design parameters
  - Results
- Conclusions

Spacer pads ?

- Fast reactor core is made by a fuel subassemblies hexagonal network.
- Spacer pads are embossed on the six faces of subassemblies above fissile zone.
- Spacer pads ensure a good clearance between subassemblies (3 mm for ASTRID)



SPX CORE ASSEMBLY

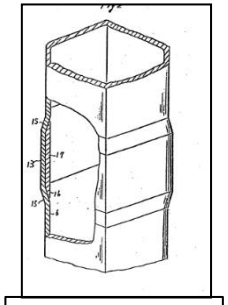


- Main constraints :
  - Most of pads must be in contact at nominal temperature
  - Extraction forces must be minimal during handling
  - **A reactivity insertion induced by core compaction must be eliminated**

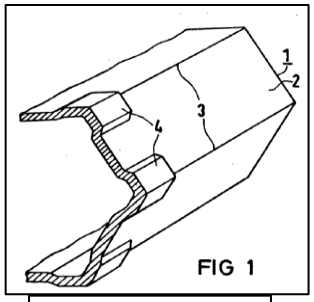
Historical overview

Spacer pads manufacturing process

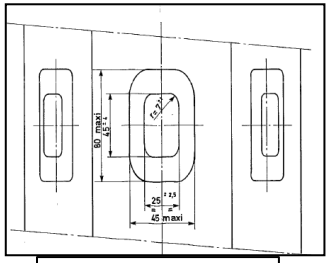
- Embossed :



Japan 1981
US4306938
FR7902619

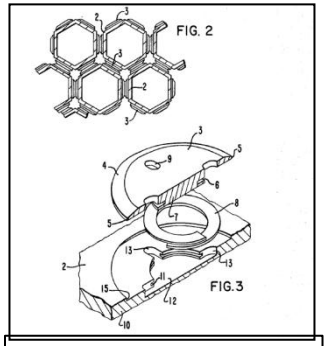


German 1985
FR2509896

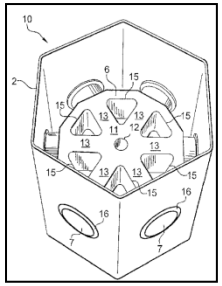


Superphenix
design 1983

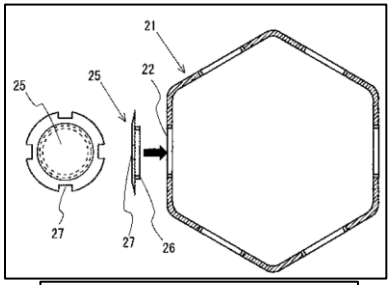
- Assembled :



US 1985
US4543233

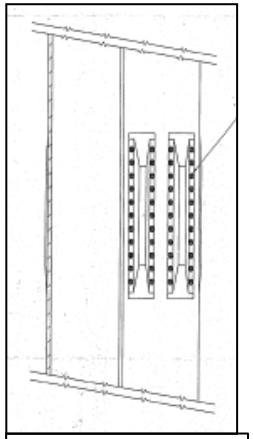


French 2008
FR0757745

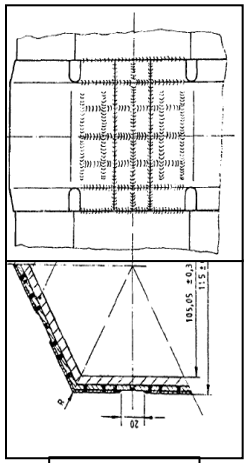


Japanese 2006
JP2006145506

- Welded : SNR300, EFR



EFR preliminary
design



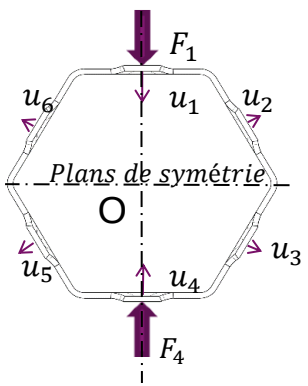
SNR 300

- A large pannel of solutions: spacer pads play a major role for the core equilibrium

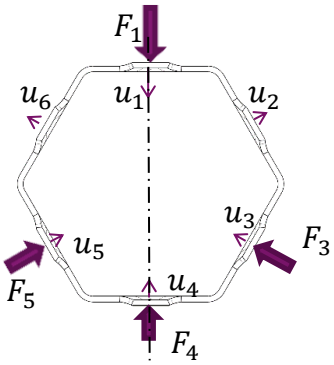
Objectives

- Start point
  - ASTRID spacer pads process = embossed surfaces
  - Safety recommandation : a reactivity insertion induced by core compaction must be eliminated

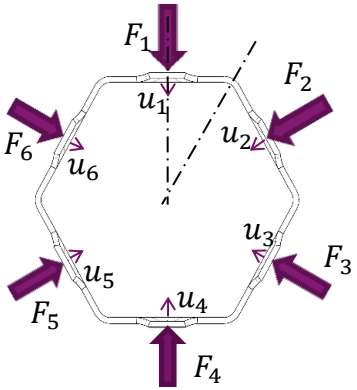
- Study objectives :
  - make a model in order to design the pads
  - Optimize the geometry in order to enhance pads stiffness
  - Associated criterion : Stiffness of spacer pads. various definitions :



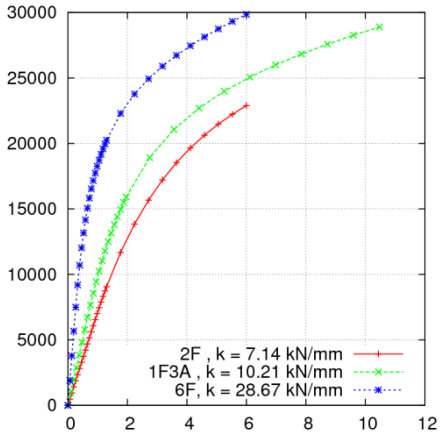
2F



1F-3A



6F

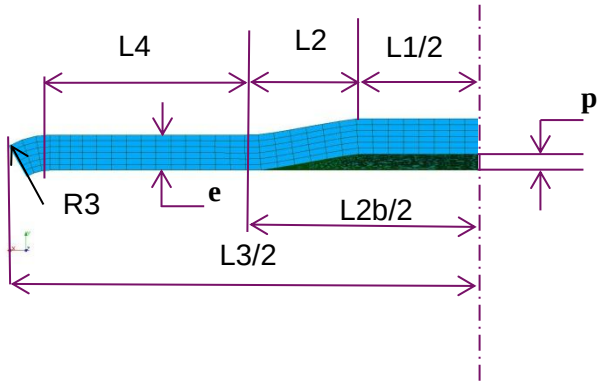


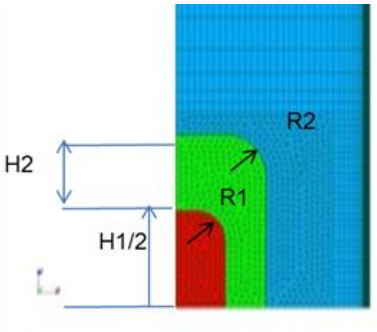
- Method :
  - make a finite element model representative of the geometry using LICOS (Cast3M- PLEIADES)
  - Validation of FE response vs. experimental crushing test on Superphenix (SPX) design
  - Use of the FE model in order to optimize geometry / stiffness

Finite element model : geometry and stamping

- Simulation of the stamping process leads to a « representative » geometry

- Design parameters :
  - H1,L1,R1 : pad contact surface
  - H2,L2,R2 : embossed zone
  - p : pad depth
  - e : hexagonal duct thickness

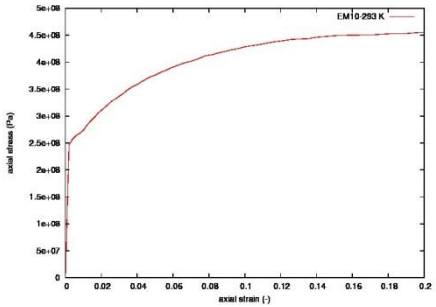


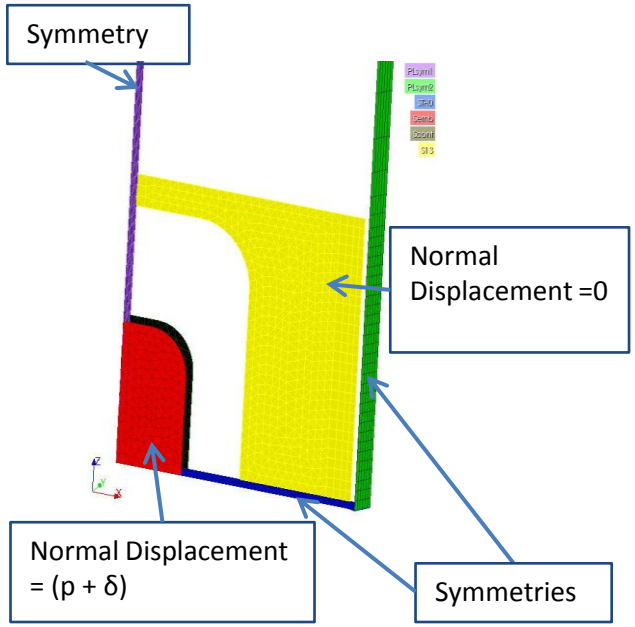


- Boundary conditions
  - Symetries ➔ 1/24 of the hexagonal duct is modelled
  - Faces of the hexagonal duct are flat at the start
  - Normal displacement annealed around embossed pad

- Stamping load :
  - Normal displacement over contact surface 0➔ (p + δ)

- Material law (Ferritic steel EM10): elastoplastic law at 20 °C





Finite element model : stamping results

- Stamping results :
  - Plastic strain :

→ Up to 15 % for SPX design (p=2,9 mm; e=4,2 mm)

→ Up to 8 % for ASTRID V2 (p=1,6 mm; e=3,6mm)

→ Strains localized in the corners and in the median plane

  - Thickness :

→ Decrease by 3% for SPX,

→ Decrease by 2% for ASTRID

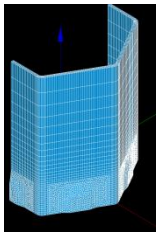
→ thickness is minimal in the median plane

→ Some cracks have occurred for SPX in this zone

→ Matrix and punch have been optimized for SPX

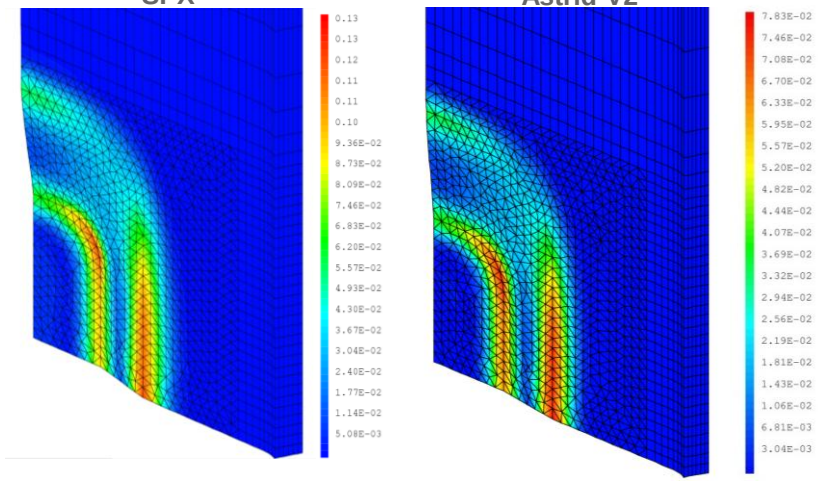
→ Stamping tests are currently performed for ASTRID

  - Deformed mesh is reproduced by symmetry in order to model each load case

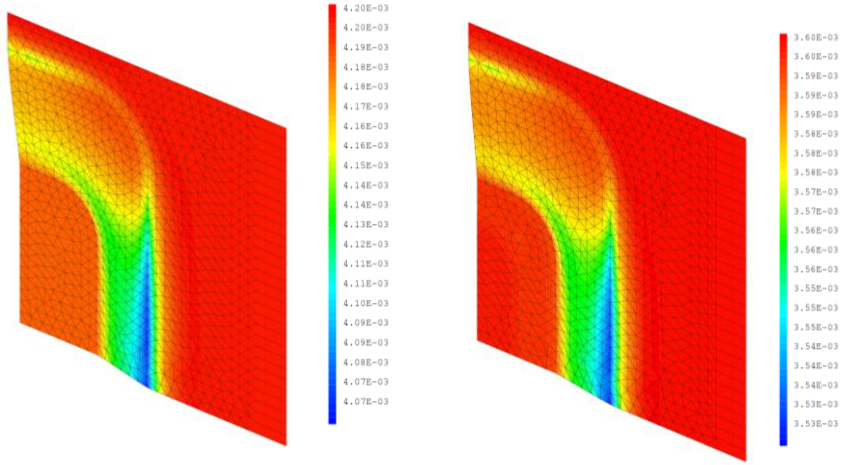


Equivalent plastic strain fields

SPX **Astrid V2**

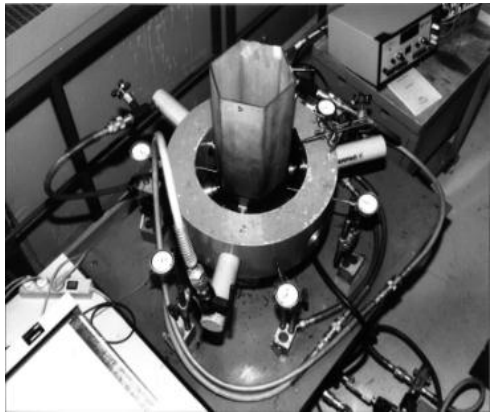


Thickness in the embossed zone

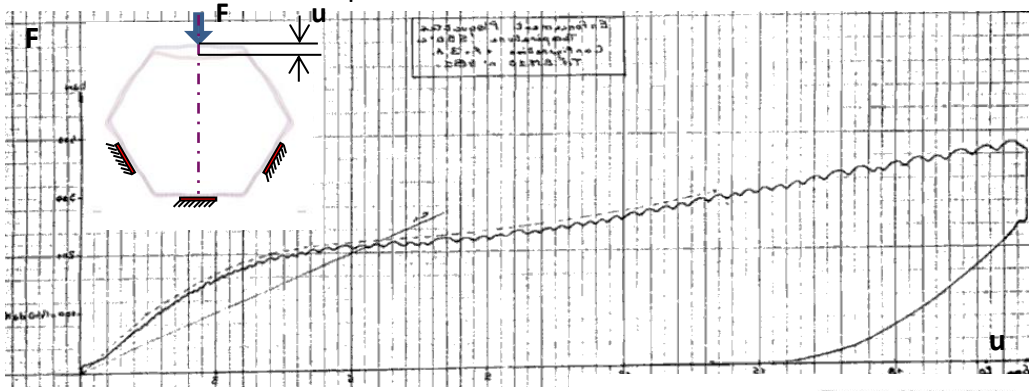


FE model: validation vs TITAN experiment

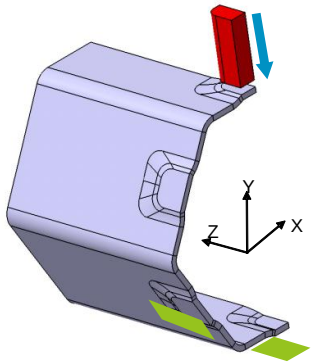
- Titan experiment:
  - Crush test performed on SPX hexagonal duct section at 550°C (1987)

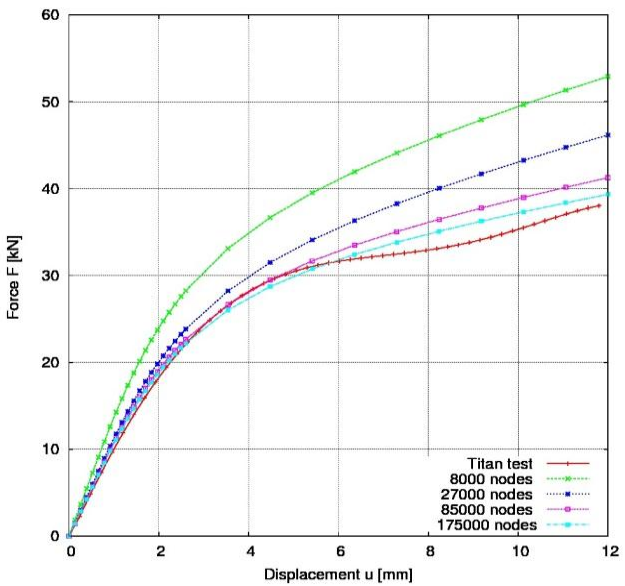


Experimental curve



- Titan simulation
  - Unilateral contacts
  - Various mesh sizes
  - Elastoplastic law at 550 °C
  - Force-Displacement curve (1F-3A)

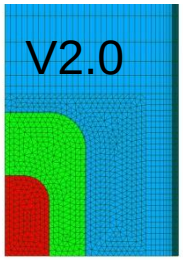


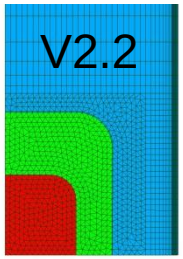


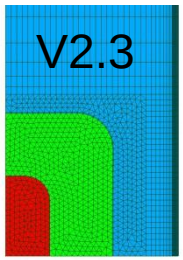
- Result :
  - Good agreement from 85 000 nodes mesh
  - Elastic stiffness obtained with an accurate precision (1%)

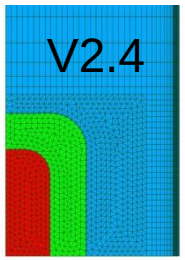
Optimization process : parameters

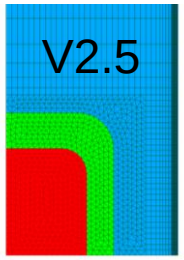
- Objective : ⬀ pads stiffness *K* in order to prevent the core compaction ($\Delta R_{core} \propto \frac{1}{\sqrt{K_{pads}}}$ => *K*x10 ➔ $\Delta R/3$)
- Parametric study: pads width, stamped zone width, pads high (e,p imposed):

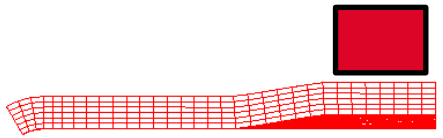






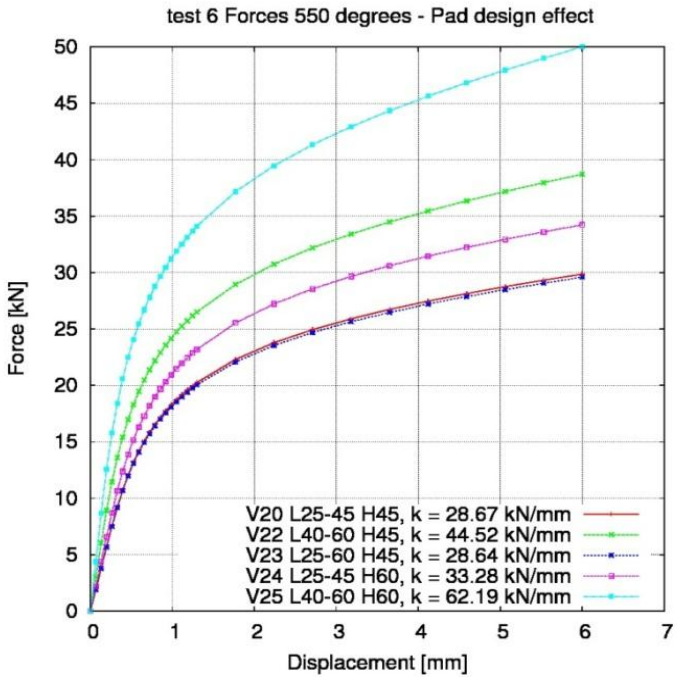






- 6F crush curves computation at 550 °C :

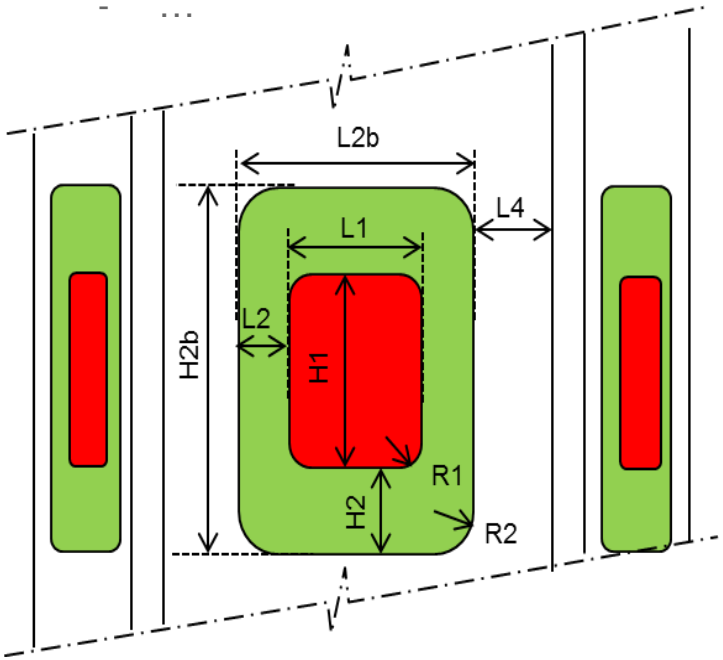
Spacer pad size effect, case 6F 550°C			
case	stiffness 6F [kN/mm]	stiffness 6F/ ref v2.0	stiffness 1F3A/ ref
V2.0	28,67	1	1
V2.2	44,52	1,5	-
V2.3	28,64	1,0	-
V2.4	33,28	1,2	-
V2.5	62,19	2,1	1,7



- stamping width doesn't influence stiffness ($k_{V2.3} \Leftrightarrow k_{V2.0}$)
- pads width have a major influence on the stiffness ($k_{V2.0} < k_{V2.2} < k_{V2.5}$)
- combination of width and height enhancement improves the stiffness by a factor 2.

Optimization process : test matrix

- What is the maximal stiffness ?
- First order parameters are used : L1, H1, R1
- All parameters variations are limited by functional conditions (manufacturing, handling, geometry)
- As examples :
  - Minimal width of flats surface between pad and duct corners is needed for stamping : L4 > 9 mm
  - Minimal stamping width because of maximal deformation rate (~15 %): L2 > 5 mm
  - Duct flats is imposed: L1 +2.L2 + 2.L4 = L3 – R3
  - …

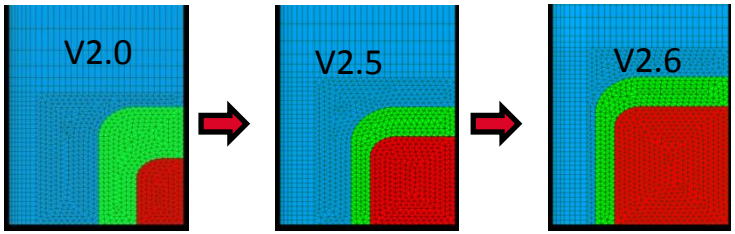


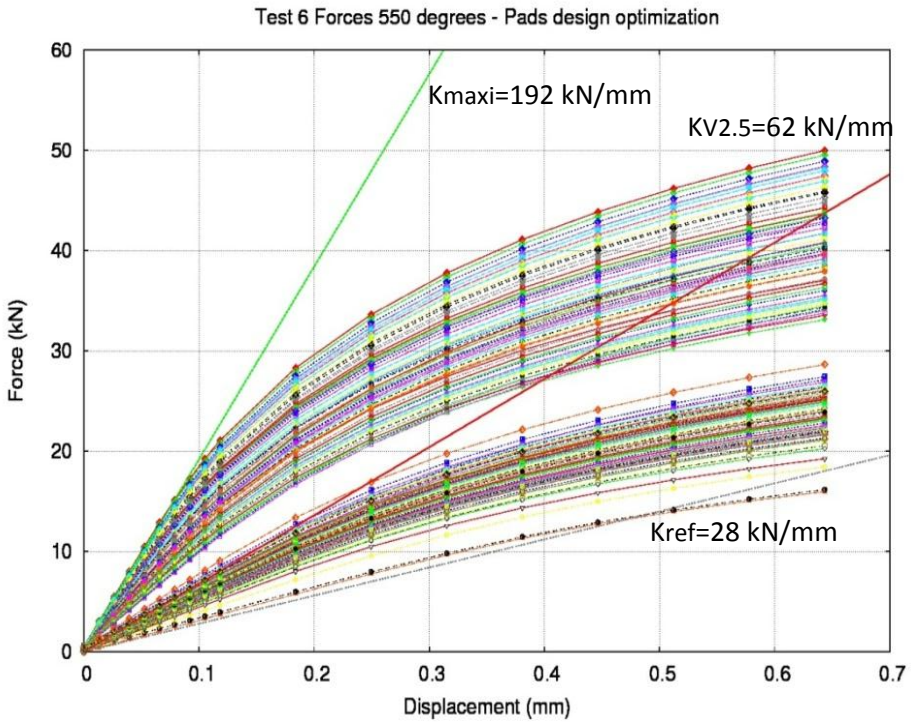
		Reference SPX V2.0	V2.5 Contact surface enlarged	Minimal value for optimization	Maximal value for optimization
Pad contact width	L1	25	40	40	60
Stamping width	L2	10	10	5	5
Total pad width	L2b	45	60	50	70
Contact pad height	H1	45	60	60	80
Stamping height	H2	17.5	10	10	10
Total pad height	H2b	80	80	80	100
Radius of pad corner	R1	7	7	7	12
Radius of matrix corner	R2	10	10	12	17

- 200 designs have been generated and stamped
- Computations of 6F crushing curves have been performed

Optimization process : results

- Results of optimization :
  - Maximal stiffness : V2.6 ($L1_{max}$, $H1_{max}$, $R1_{min}$)
  - Stiffness max X 7 / ref v2.0
  - L2 minimal, R2 minimal, H2 minimal





- Stiffness enhanced, but we must check :
  - Hydraulic flow between subassemblies ➔ simulations of transients of loss of flow
  - Feasibility of forming process (embossed zone plastic rate=17 % for v2.6)
    ➔ tests in progress on EM10 plates
  - Extraction forces of subassemblies ➔ $F \propto K$ (cf paper #456 Lamagnère et al.)

Conclusions

- Summary
  - A finite element model representative of spacer pads has been developped
  - FE model figure out the stamping process
  - FE model compute the stiffness and the crush curve with accuracy

  - Stiffness of the spacer pads can be simply enhanced until a factor 7
  - Maximal stiffness of embossed spacer pads is ~200 kN/mm for a 6F load case
  - we must maximize spacer pads width

- Future
  - FE model will be employed for stress evaluation and sizing
  - Validation of FE model by new crush test performed at IGCAR
  - Validation of feasibility of the stamping process (in progress)
  - Impact of hardening rate on EM10 properties (in progress)
  - Impact of larger spacer pad on the hydraulic behaviour during transients of loss of flow
  - Optimization between an high stiffness and low extraction forces

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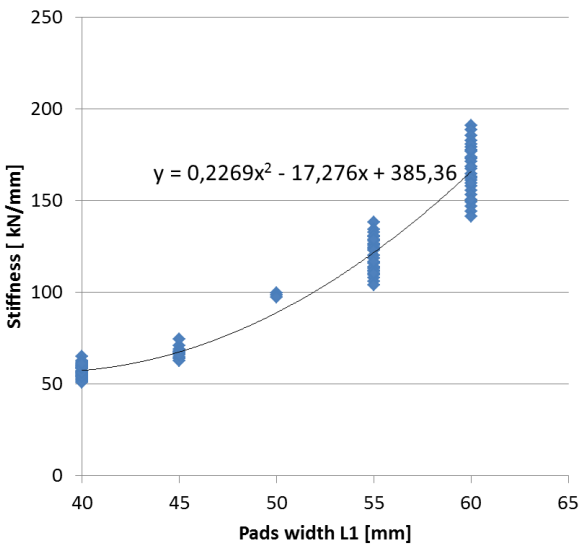
Thank you for your attention

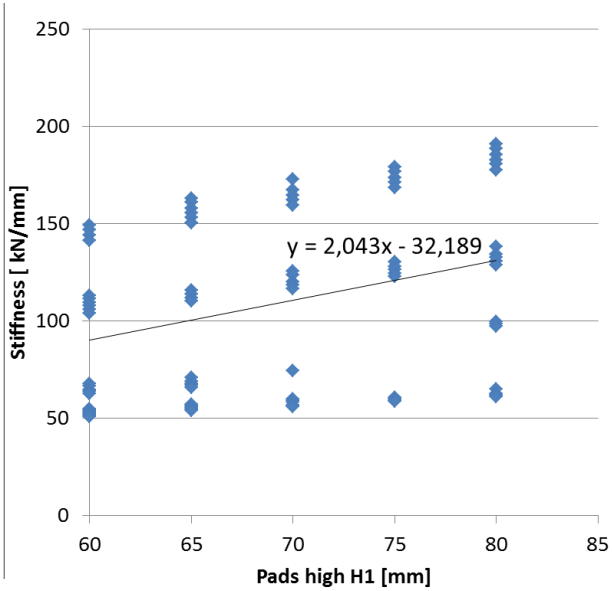
Questions ?

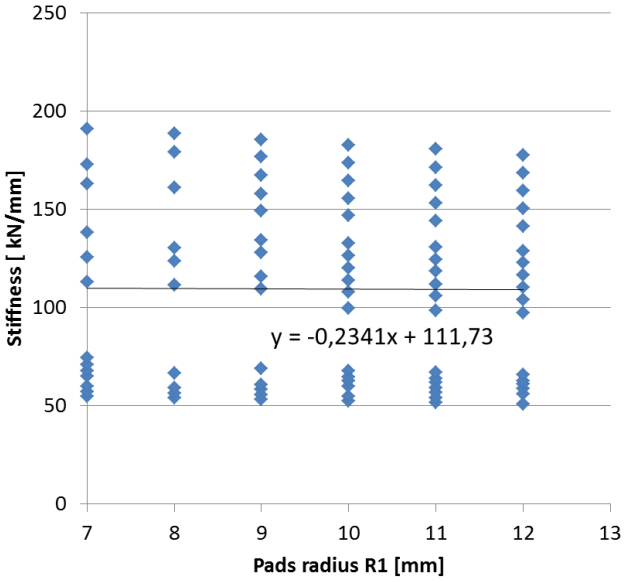
Contact : V. Blanc
victor.blanc@cea.fr
CEA Cadarache, DEN/DEC/SESC, F-13108 Saint-Paul-lez-Durance, France

Back up slide : Optimization process, results

- Results of simulations :
  - Parameters influences : $\mathrm{K} \propto L1^2$, $\mathrm{K} \propto H1$, $\mathrm{K} \propto -R1$

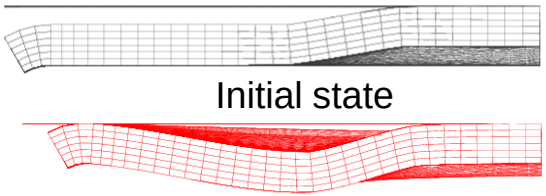






Back up slide : Stiffness after spacer pads crushing

- Contact model Hexagonal duct –Hex. duct :
  - a normal displacement condition between HD external face and a plane figure out the real contact
- Simulation of 6F case for spacer pads design V2.0

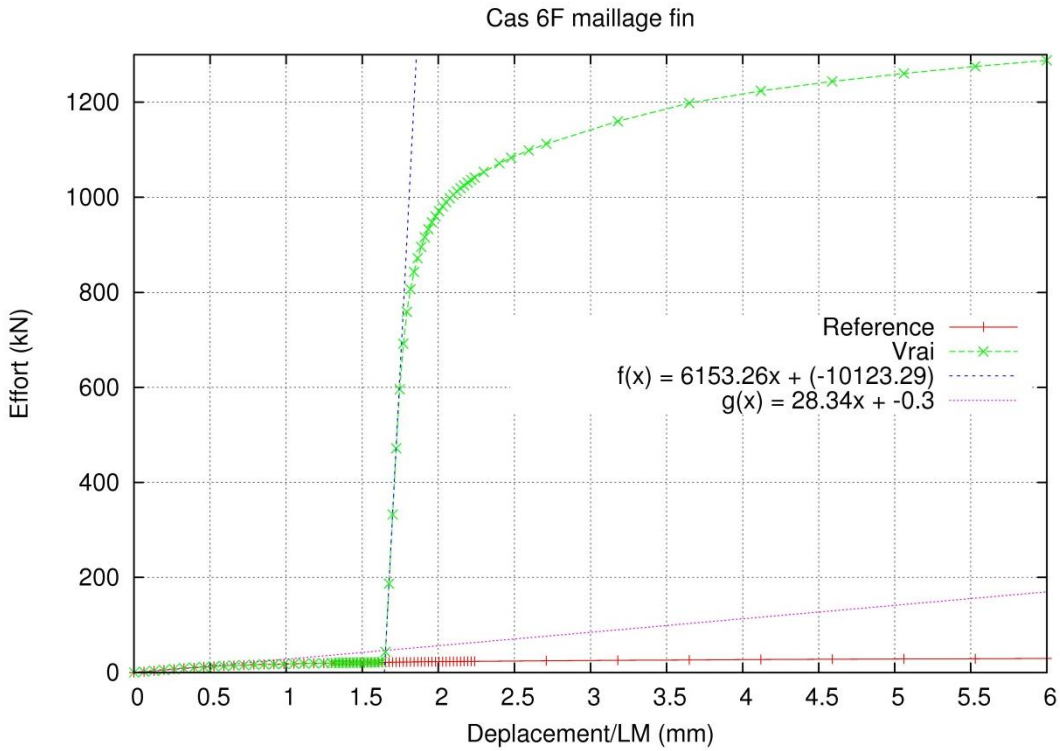


Initial state

Final state

1st phase (d < 1,6 mm) : contact such as a punch-pad contact
k_{6F} = 28 kN/mm

2nd phase (d > 1,6mm) : contact on duct corners
$k_{6F\text{-}HDHD}$ ~6000 kN/mm



- NB : 6F case is the stiffer case of spacer pads loading