



Characterization, simulation and improvement of spacer pads mechanical behaviour for sodium fast reactor fuel subassemblies

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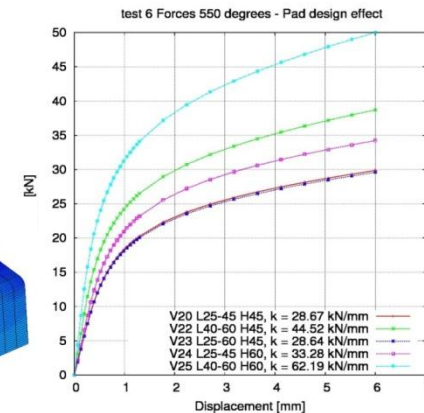
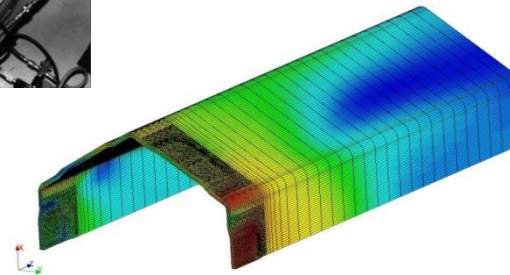
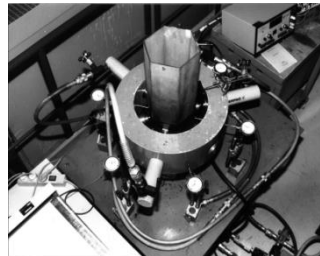
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Characterization, Simulation and Improvement of Spacer Pads Mechanical Behaviour for Sodium Fast Reactor Subassemblies



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

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France

- Introduction
 - Spacer pads
 - Historical overview
 - Objectives

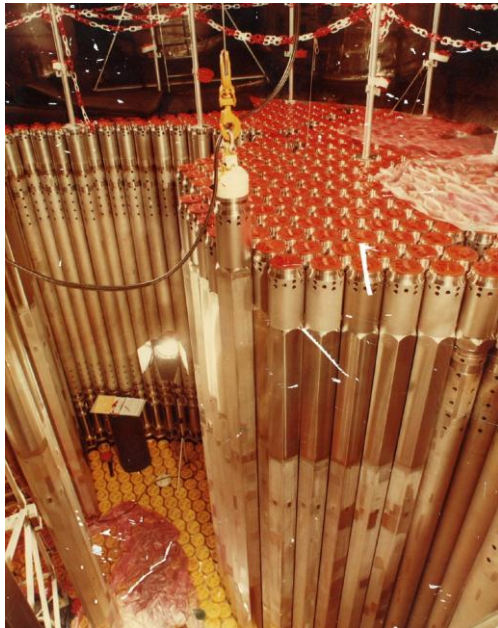
- Finite element model construction and validation
 - Geometry and stamping
 - Stamping simulation
 - Titan experiments and simulation

- Optimization process
 - Design parameters
 - Results

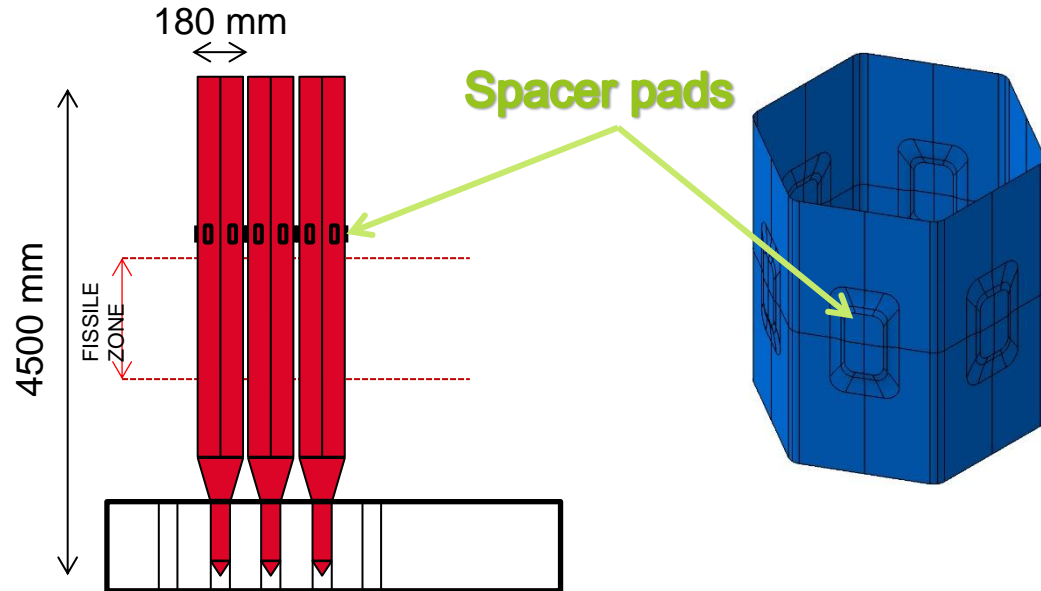
- Conclusions

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



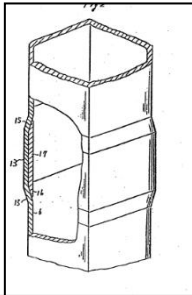
■ Main constraints :

- 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**

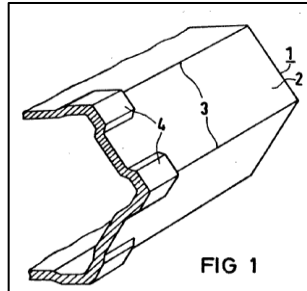
Historical overview

Spacer pads manufacturing process

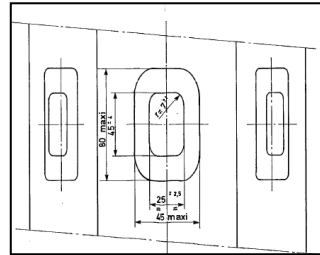
■ Embossed :



Japan 1981
US4306938
FR7902619

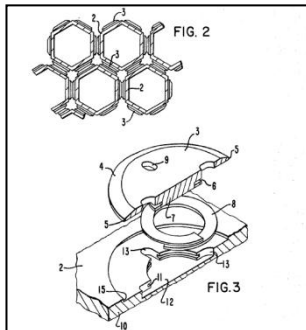


German 1985
FR2509896

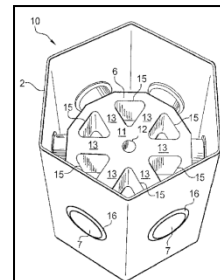


Superphenix
design 1983

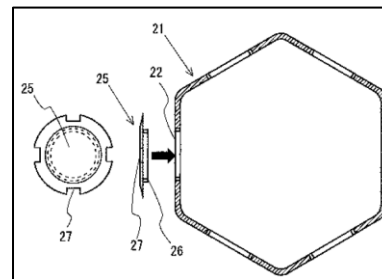
■ Assembled :



US 1985
US4543233

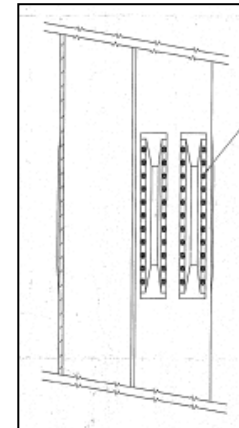


French 2008
FR0757745

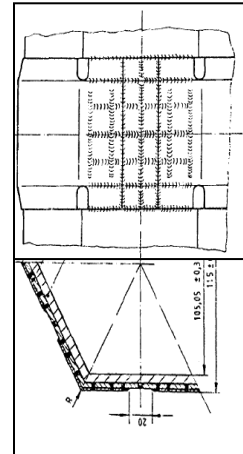


Japanese 2006
JP2006145506

■ Welded : SNR300, EFR



EFR preliminary
design

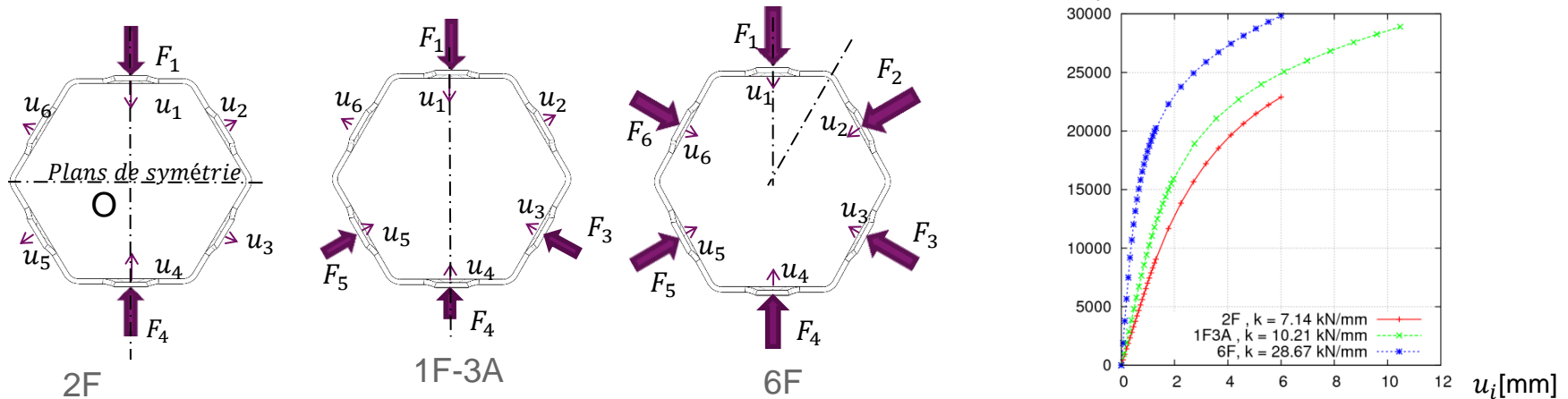


SNR 300

■ A large panel 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 : $F_i[N]$

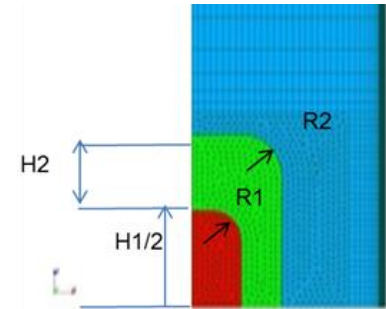
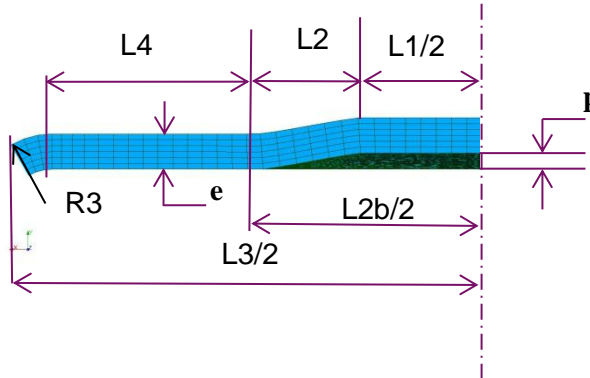


- Method :
 - make a finite element model representative of the geometry using LICOS (Cast3M- PLEIADES)
 - Validation of FE response vs. experimental crushing test on Superphenix (SPX) design
 - Use of the FE model in order to optimize geometry / stiffness

Finite element model : geometry and stamping

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

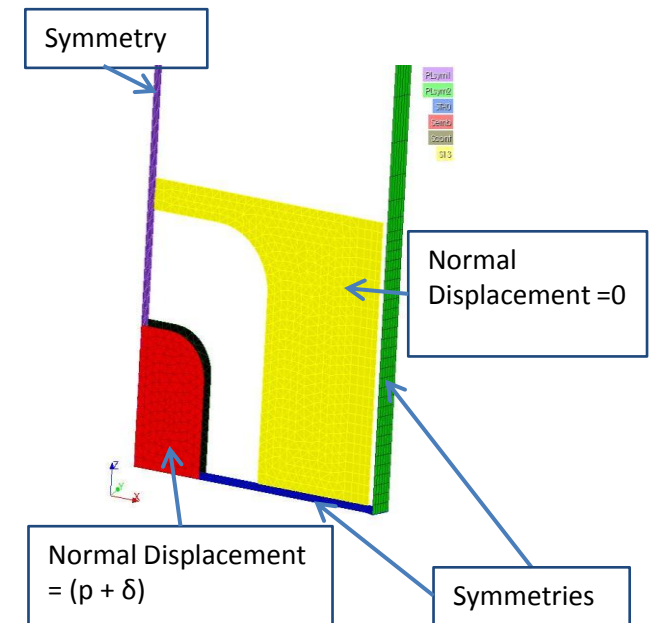
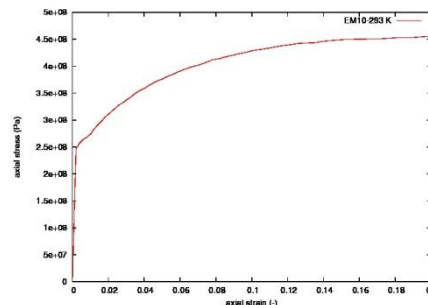
- Design parameters :
 - $H1, L1, R1$: pad contact surface
 - $H2, L2, R2$: embossed zone
 - p : pad depth
 - e : hexagonal duct thickness



- 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 $0 \rightarrow (p + \delta)$

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



Finite element model : stamping results

Stamping results :

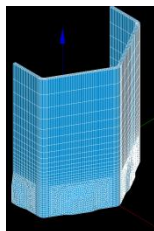
Plastic strain :

- Up to 15 % for SPX design ($p=2,9$ mm; $e=4,2$ mm)
- Up to 8 % for ASTRID V2 ($p=1,6$ mm; $e=3,6$ mm)
- Strains localized in the corners and in the median plane

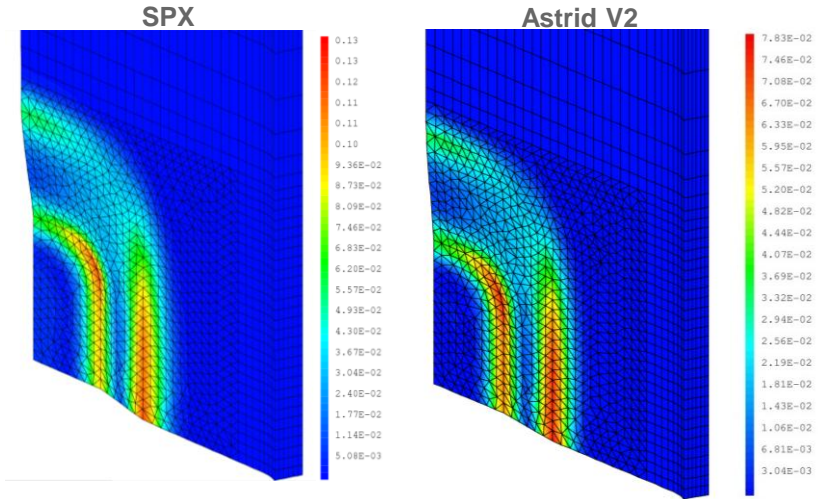
Thickness :

- 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

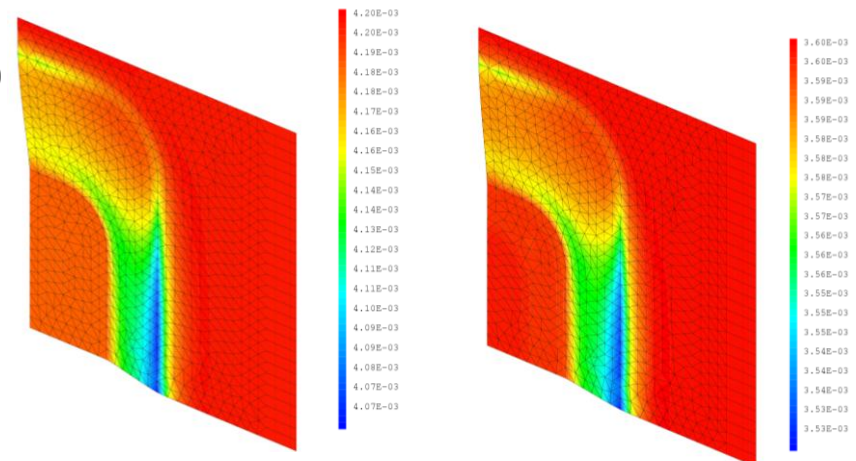
- Deformed mesh is reproduced by symmetry in order to model each load case



Equivalent plastic strain fields



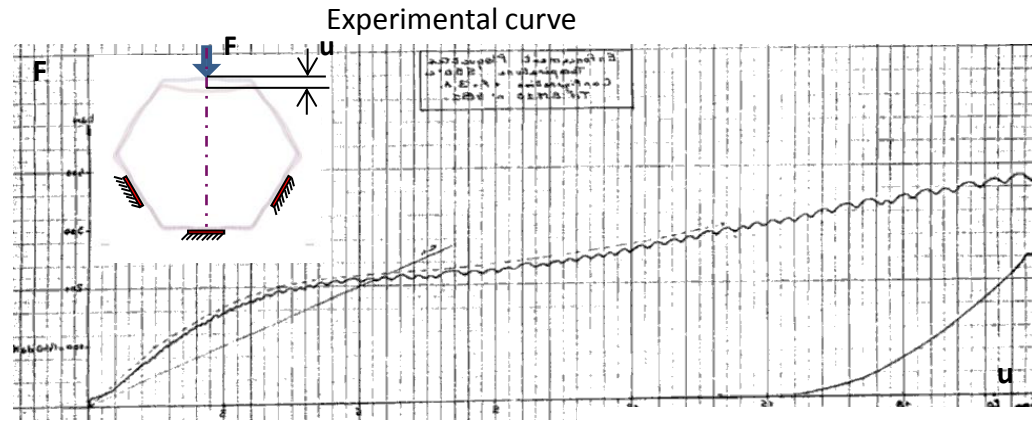
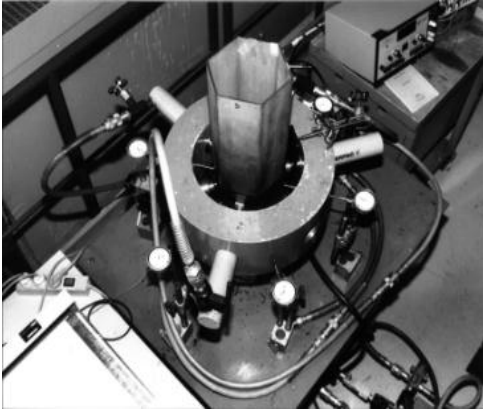
Thickness in the embossed zone



FE model: validation vs TITAN experiment

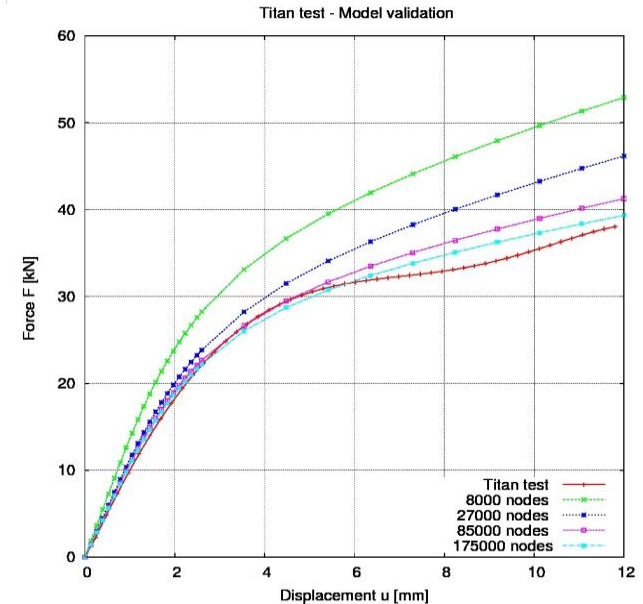
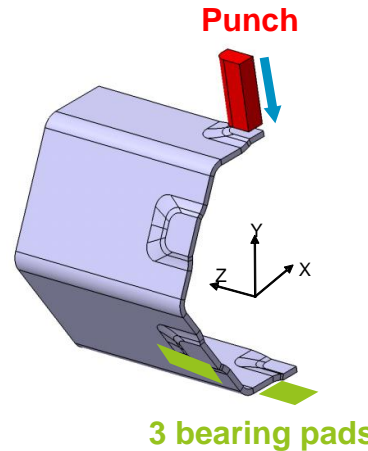
Titan experiment:

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



Titan simulation

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

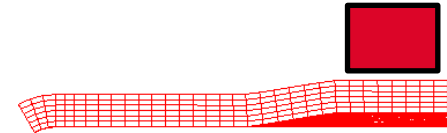
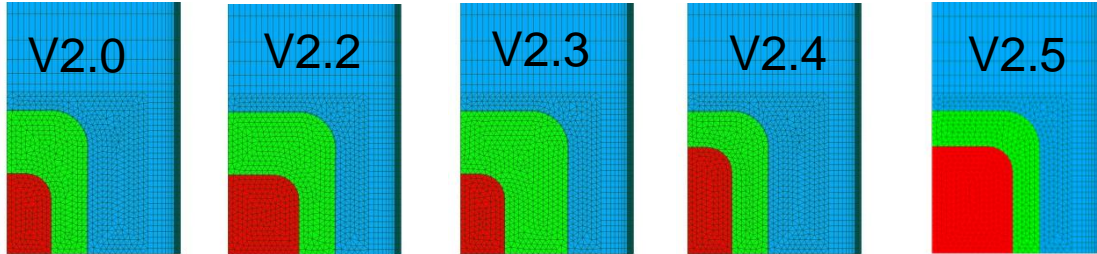


Result :

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

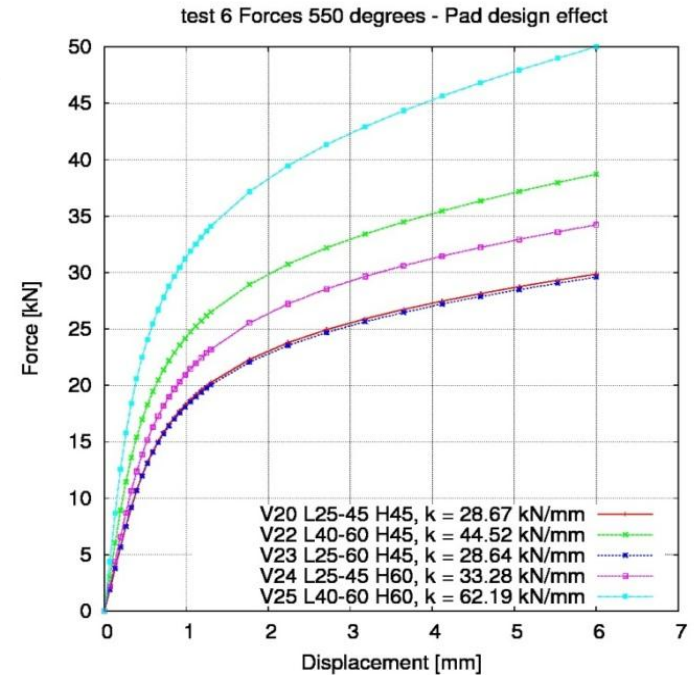
Optimization process : parameters

- Objective : ↗ pads stiffness K in order to prevent the core compaction ($\Delta R_{core} \propto \frac{1}{\sqrt{K_{pads}}} \Rightarrow K \times 10 \rightarrow \Delta R/3$)
- Parametric study: pads width, stamped zone width, pads high (e,p imposed):



- 6F crush curves computation at 550 °C :

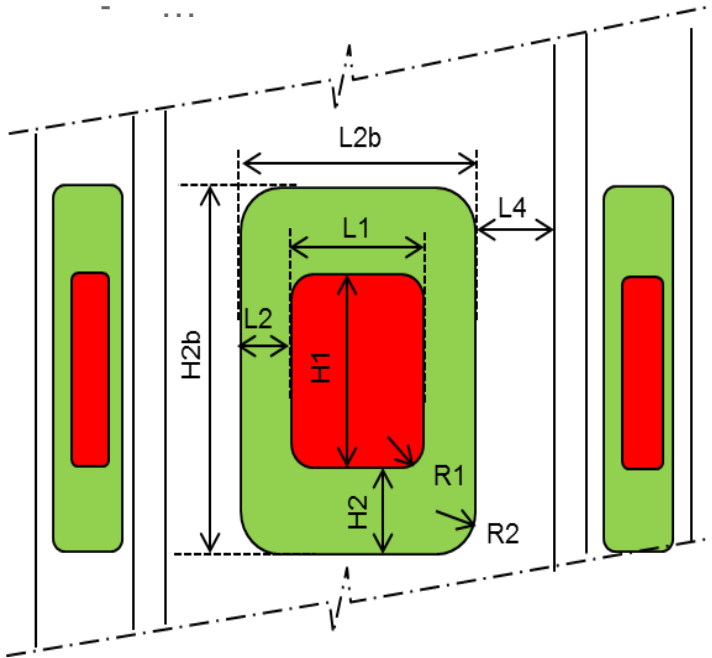
Spacer pad size effect, case 6F 550°C			
case	stiffness 6F [kN/mm]	stiffness 6F/ ref v2.0	stiffness 1F3A/ ref
V2.0	28,67	1	1
V2.2	44,52	1,5	-
V2.3	28,64	1,0	-
V2.4	33,28	1,2	-
V2.5	62,19	2,1	1,7



- 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 : $L4 > 9 \text{ mm}$
 - Minimal stamping width because of maximal deformation rate ($\sim 15 \%$): $L2 > 5 \text{ mm}$
 - Duct flats is imposed: $L1 + 2.L2 + 2.L4 = L3 - R3$
 - ...

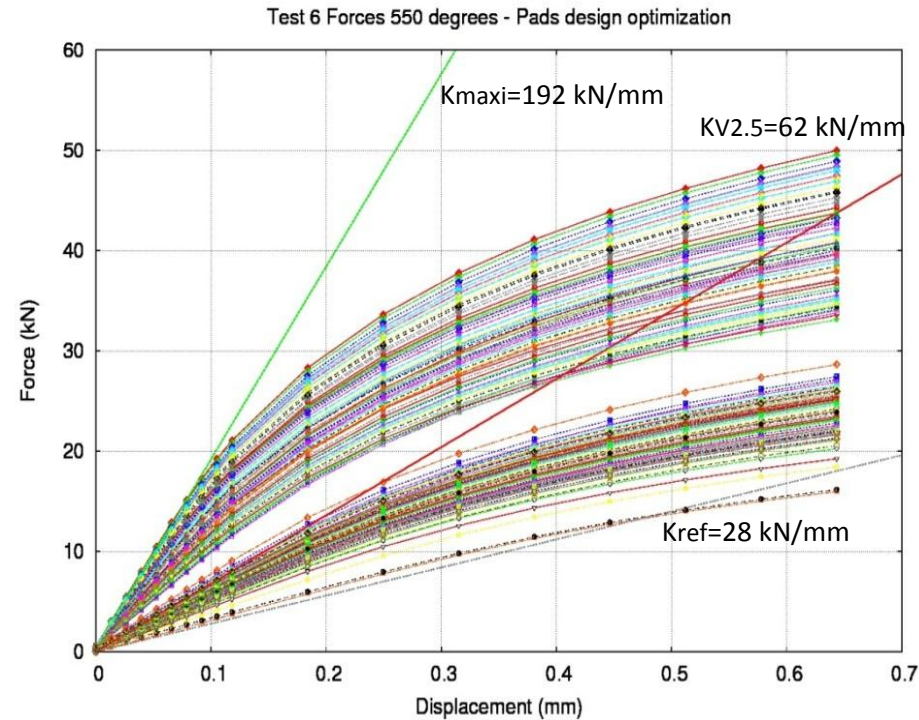
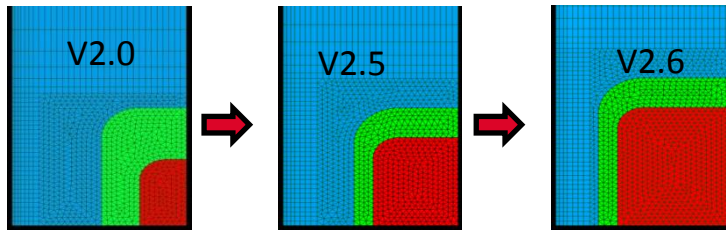


		Reference SPX V2.0	V2.5 Contact surface enlarged	Minimal value for optimization	Maximal value for optimization
Pad contact width	L1	25	<u>40</u>	40	60
Stamping width	L2	10	10	5	5
Total pad width	L2b	45	<u>60</u>	50	70
Contact pad height	H1	45	<u>60</u>	60	80
Stamping height	H2	17.5	<u>10</u>	10	10
Total 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 developed
- 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 ?

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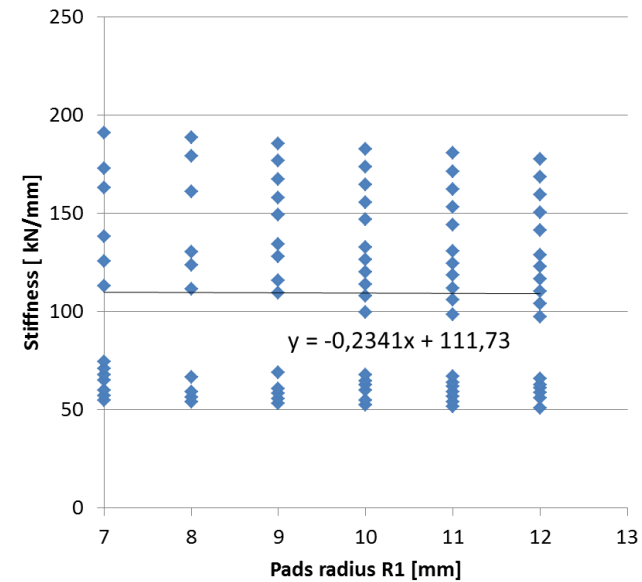
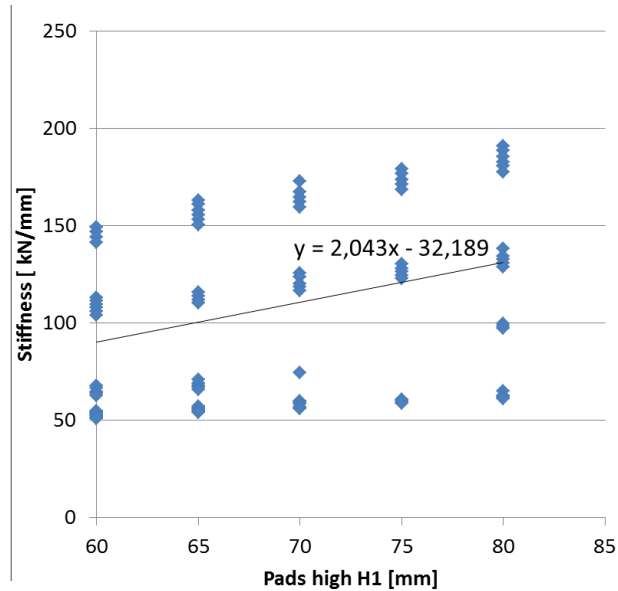
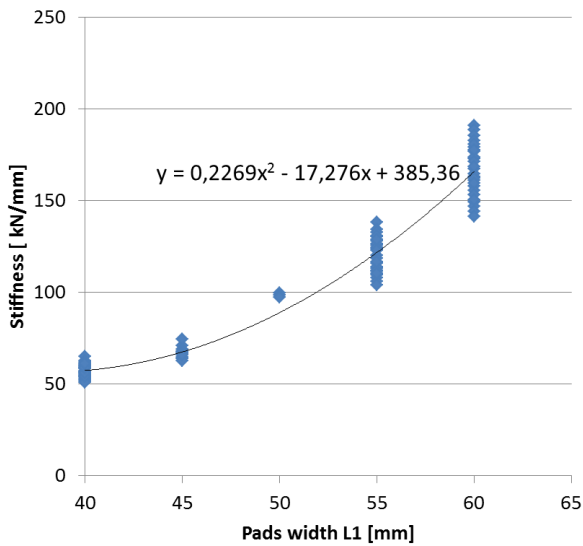
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Back up slide : Optimization process, results

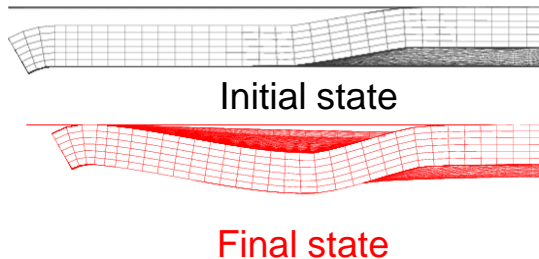
Results of simulations :

Parameters influences : $K \propto L1^2$, $K \propto H1$, $K \propto -R1$



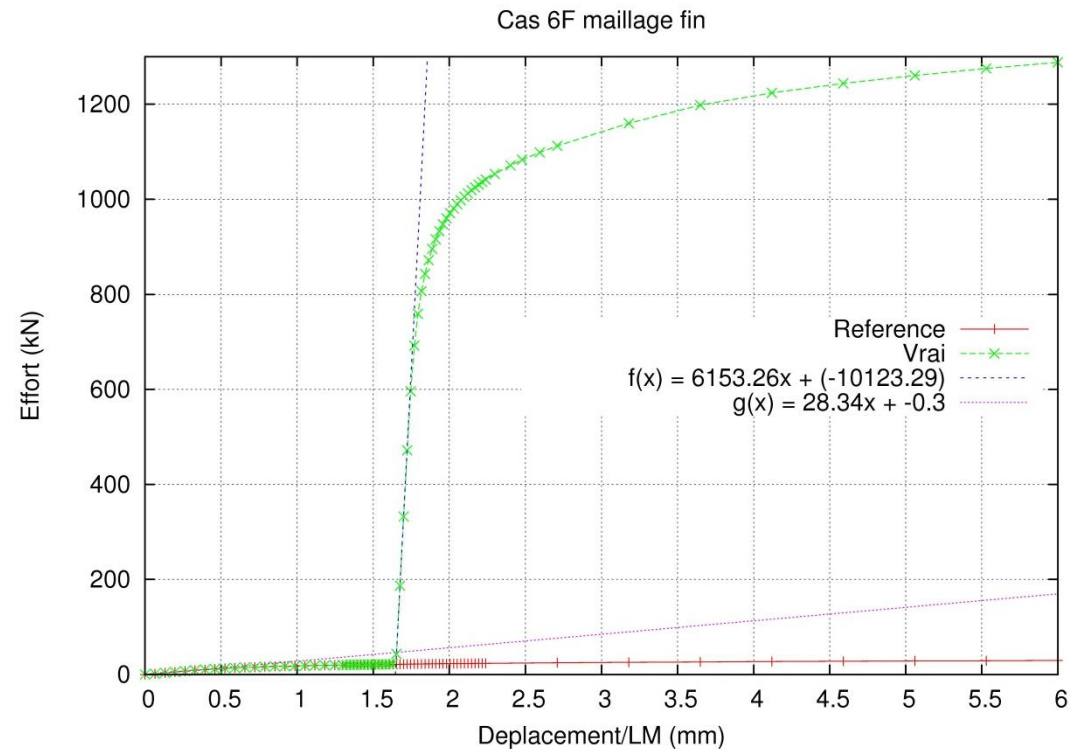
Back up slide : Stiffness after spacer pads crushing

- 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



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

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



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