

Prediction of failure on high strength steel in seat mechanisms simulation

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Abstract:

Tracks are the mechanisms which enable to translate the seat; they are key contributors in occupant safety as link between seat and car. With the current evolution of ecologic legislation, one of major automotive industry priorities is to decrease the product mass. To reach this objective, the use of high strength steels appears as a good solution with the drawback to be more brittle. In parallel, FEA models have to be more and more predictive in order to reduce the validation cost.

In this context, rupture risk prediction appears as a strong need from design office and usual post-processing methods are not accurate enough to bring sufficient support to design teams.

The solution chosen is a coupling between Ls-Dyna and the failure criteria crachFEM developed by MatFem Company. The evaluation of this risk is based on plastic strain evolution and stress state of the element. The methodology requires a specific characterization of the material to get information about the failure for different stress states.

First application has been launched on ultimate strength subsystem on track. With dual-phase material, primary track failure mode is generally a profile rupture. First results highlighted correctly the area of rupture, but the ultimate strength was generally higher in FEA model than in the hard-test. This gap can be explained by the difference of scale between characterization of failure, which is a very local phenomenon, and the evolution of strain in simulation which is dependant of mesh size. Industrial crash model requirement (best compromise between accuracy and computation time: around 3mm mesh size) doesn't permit to use mesh size needed for accurate rupture prediction. So "hybrid" modeling has been developed in order to have mesh size appropriate to MatFem analysis in useable computation time.

With this approach the ruptures are well identified in term of areas, kinematics & ultimate strengths. Nowadays we are able, on this product, to predict with accuracy a risk of rupture on subsystem or on complete seat crash test.

Keywords: Mechanisms simulation; Dual-phase material; Rupture; CrachFEM.

Summary

1) Introduction:	3
2) Actual Problematic	3
3) CrachFem Presentation	4
4) Application on industrial sub system case	5
a) Model presentation	5
b) First CrachFem result	6
c) Patch approach	7
5) Work flow strategy	9
6) Validation on complete seat Crash	10
7) Prospect	11
a) In coming actions	11
b) Future actions	11
8) Conclusion	12

1) Introduction:

Seat structures play a major role in the car passive safety. Due to their adjustment function mechanisms are generally involved in the seat failure mode. The topic of this paper concerns the mechanisms used for longitudinal adjustment, the “tracks system”.

During last years, the ecologic legislations have led to lot of changing in the automotive industry strategy. Nowadays one of the main priorities is the reduction of car weight without impact on safety or cost. To fulfill this need, the global approach goes through a structure optimization and the use of high strength steel material.

This kind of material has generally the drawback to have a more brittle behavior. Rupture is now more present during development phase.



Naturally, FAE tools provide a strong support to face this challenge. In this aim, FEA models have to be

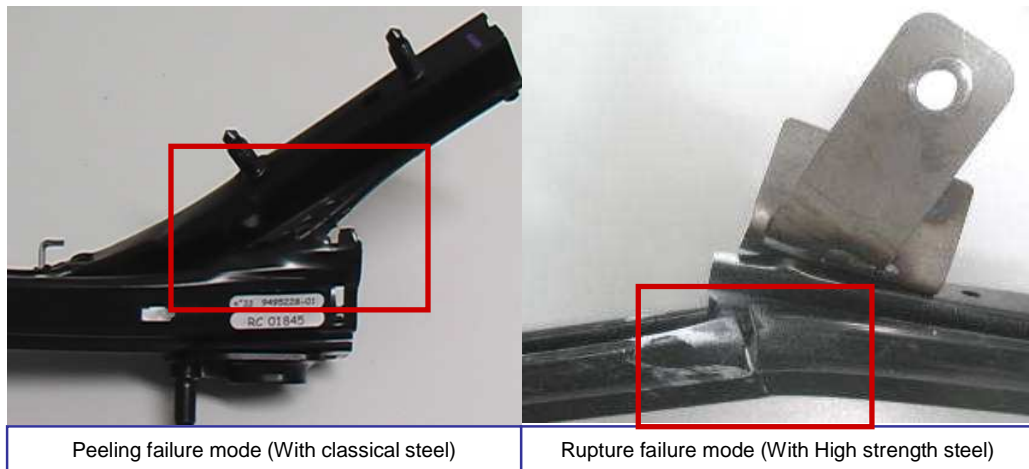
more and more predictive. Faurecia is developing methodologies, standardize its modeling, and improve its material knowledge in order to improve the accuracy level of simulations and in this way reduce validation cost.

The next step, in this continuous improvement, is an accurate rupture prediction. In the past some criteria based on experience and equivalent plastic strain have permit to conclude on *potential risk* of rupture. The aim off this work is to develop a method to use a rupture criterion called CrachFem in order to anticipate the product rupture and improve the optimization work flow.

The first action will be launched on tracks and will be generalized in a second time to complete seat product. The industrial context of this study obliges to keep in mind a strong constraint which is the “reactivity time”.

2) Actual Problematic

In tracks since the using of high strength steel, the failure mode type has changed. With “classical” material ($A_{80}\% \sim 20\%$) the failure mode generally observed is the disassembly of the rails which compose the tracks, called *peeling*. The more brittle behavior of the high strength steels ($A_{80}\% < 10\%$) generally induces rupture (see picture 2).



Picture 2 Tracks System failure modes

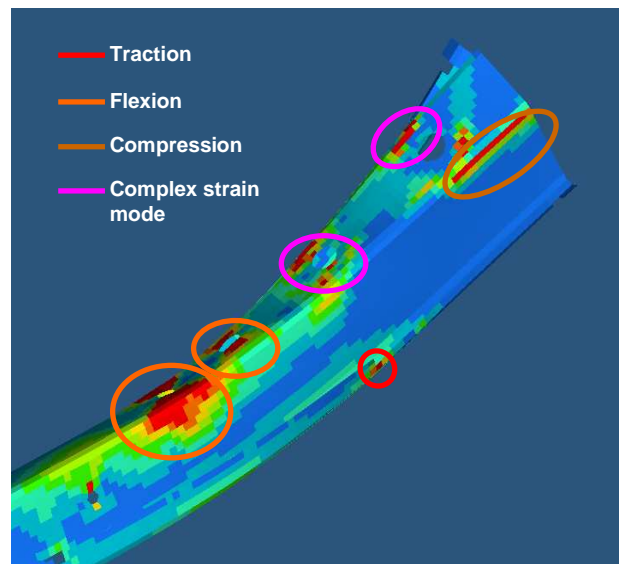
The actual estimation of the rupture is based on equivalent plastic strain, orientation of principal strains and on the experience of the project engineer. This estimation gives correct result for deformation in traction mode, but the conclusion becomes quickly difficult when the elements are in flexion, torsion, or more complex strain mode. Moreover the strain path can not be taken into account.

In the next example, strains over $A_{80}\%$ value are highlighted in the circles. But only the red one is mainly in traction and can result in a risk evaluation.

On the other areas, it is not possible to reach a direct conclusion without project experience.

One hypothesis based on Faurecia experience is that, with our standard mesh size a

rupture in traction can occur near the $A_{80}\%$, but the other modes will sustain higher equivalent strain value.



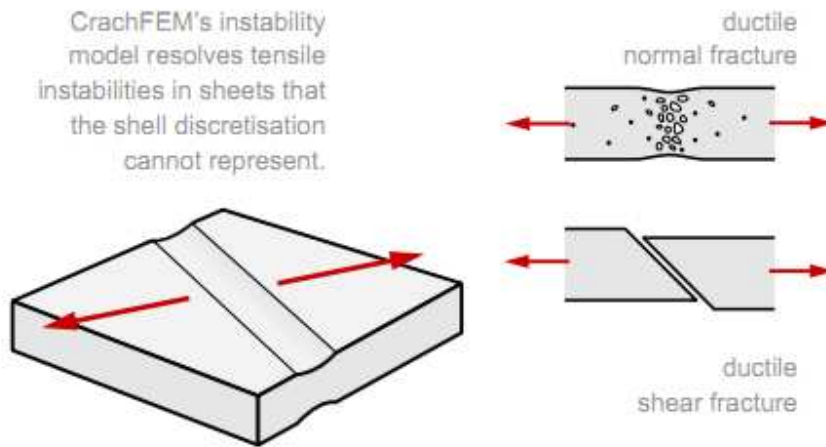
3) CrachFem Presentation

CrachFem is a rupture criteria running in parallel with explicit FEA solvers as a user material model. CrachFem takes into account the different mechanisms responsible for the rupture in steel material, instability necking, normal ductile fracture (generated by growth and coalescence of voids) and shear ductile fracture (generated by shear band localization).

The criterion is defined for normal and shear fracture by a function of equivalent strain and the stress state. The 3D stress state is determined as a function of triaxiality and the ratio

$$\frac{\sigma_1}{\sigma_{equ}} \text{ for normal fracture and } \frac{\sigma_1}{\tau_{max}} \text{ for shear fracture.}$$

Prediction of failure on high strength steel in seat mechanisms simulation



Picture 4 CrachFem criteria presentation

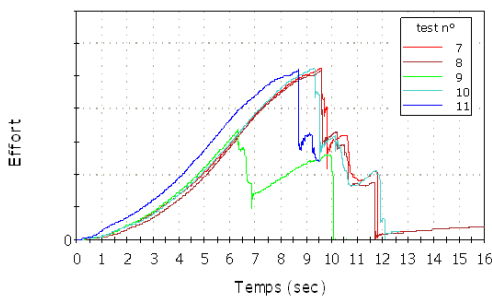
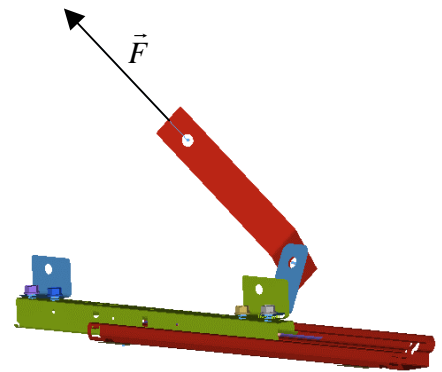
The fracture curves are determined experimentally by local measurement of rupture strain. The samples used have been determined in order to cover a maximum of the strain state range in shear and normal fracture.

4) Application on industrial sub-system case

a) Model presentation

Currently during project life, subsystem tests are realized on some specific parts. On tracks for example, a quasi-static test which represents the effort generated on the belt during a crash will give information on product performance. The effort is applied until failure of the product. As seen in introduction, rupture has become an important failure mode.

Actual analysis does not permit to identify with accuracy the real rupture area and the ultimate strength at rupture. In order to evaluate CrachFem failure criteria in our application, physical tests and virtual test with the same configuration (material, design, boundary conditions ...) have been compared.



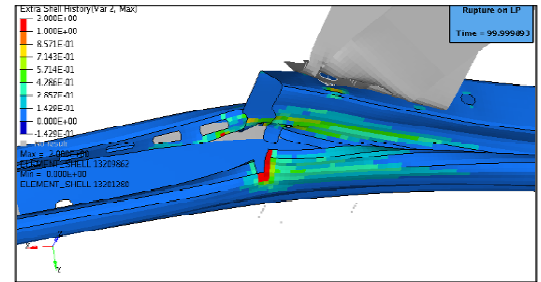
The graph (picture 6) shows the physical results of the 5 tests done on this configuration. Except the n°9, excluded of the analysis, the repeatability of test is really good. The failure mode is the rupture of the lower rail (Red part in the picture 5)



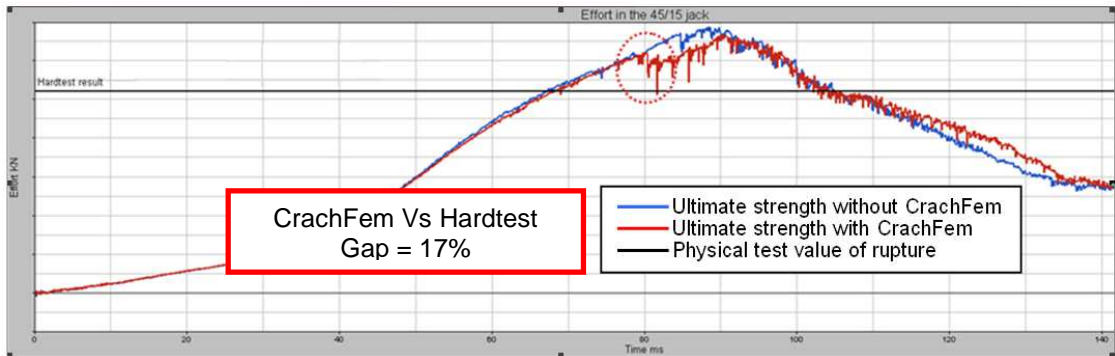
b) First CrachFem result

On this model, with CrachFem, the rupture area is well identified (Picture 7 compared to Picture 8). But the ultimate strength corresponding to the first element deleted is too high. As shown in picture 9, a gap of 17% between physical average value and CrachFem rupture information is highlighted.

CrachFem characterization is based on some sample tests with different state of stress. For each of them the strain at the rupture is measured with very local measurement of this strain, generally directly calculated from the fracture surface measurement. But, due to strain concentration in the rupture area, the strain value increases a lot. To reach the rupture a high strain level (compare to $A_{80}\%$ criteria) is needed.



Picture 8 Virtual sub-system rupture area



Picture 9 Ultimate strength comparison with & without CrachFem

Example with the case of the pure uniaxial traction state of stress:

Extracted from the theoretical CrachFem manual, in the ductile normal fracture criteria

the state of stress is defined by: $\beta = \frac{1 - s\eta}{\sigma_1 / \sigma_{VM}} \rightarrow \text{with } \eta = \frac{-3p}{\sigma_{VM}}$

p = hydrostatic pressure

σ_{VM} = Von mises Stress

η = Stress triaxiality

s = Triaxiality weighing

In case of pure traction $\sigma_{VM} = \sigma_1$ and $p = \sigma_1 / 3 \rightarrow \beta = 1 - s$

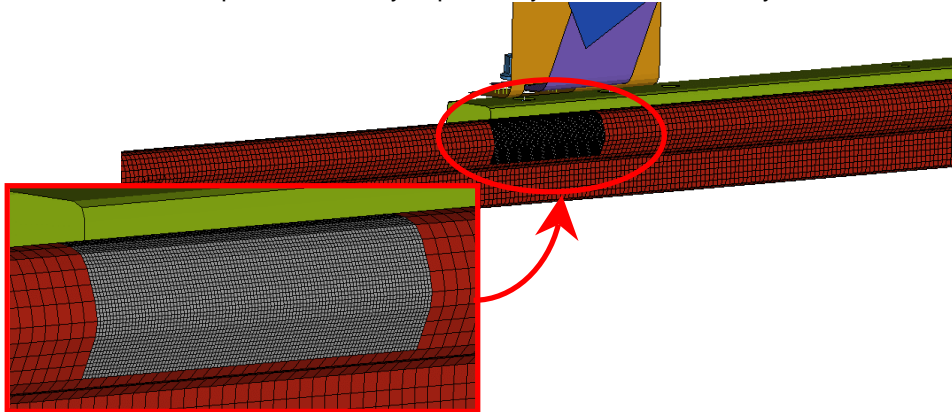
So the rupture strain for our load case is $\epsilon^{**} = d.e^{q\beta} = 0.94$
(d and q an s = CrachFem parameters characterized for tracks material)

To reach the rupture in uniaxial tension the equivalent strain has to be equal to 94% which is high value compared to old rupture analysis based on $A_{80}\%$ (on this material = 9%)

The standard mesh size used in Faurecia simulation is enclosed between 2 and 3 mm which is too coarse to describe correctly this kind of localized deformation. The solution proposed is to decrease locally the mesh size in the rupture area.

c) Patch approach

Reducing drastically the mesh size in the whole part is not usable in a complete seat crash model due to development reactivity imposed by automotive industry.



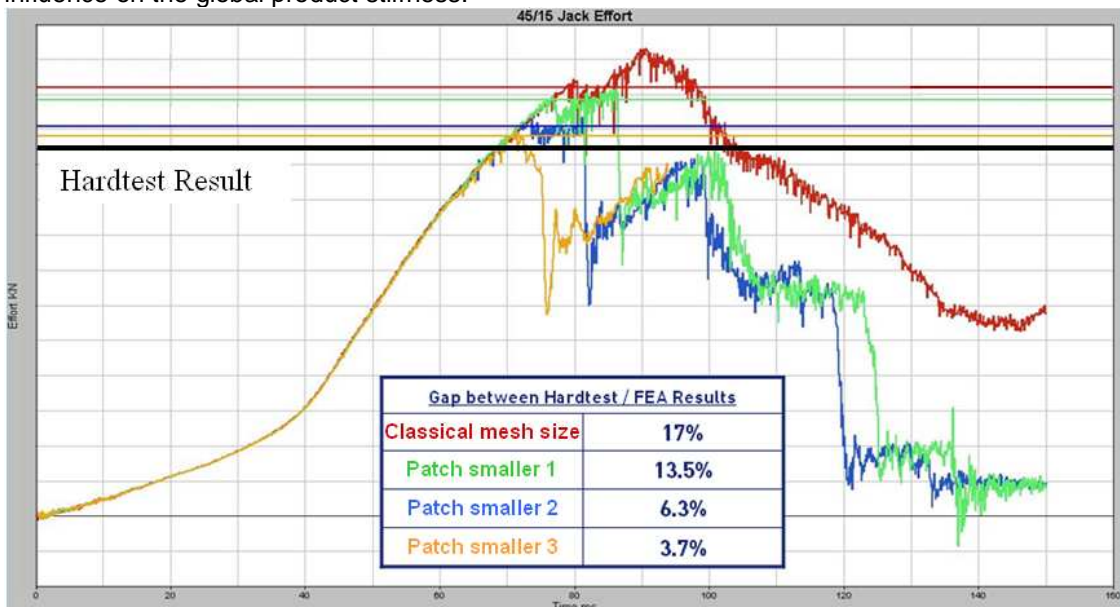
Picture 10 Patch on tracks model

The hybrid coarse/fine approach by a patch implementation is a good compromise. The patch replaces a portion of the “coarse” mesh in the fracture area. The borders of the patch have to be far enough from the studied area to avoid any pollution in the fracture detection.

The link between both meshes is made by a tied contact. The specific tied called “`tied_shell_edge_to_surface_beam_offset`” insures the link between all nodes degrees of freedom. The experience shows that this tied keeps a good continuity in the stress fields.

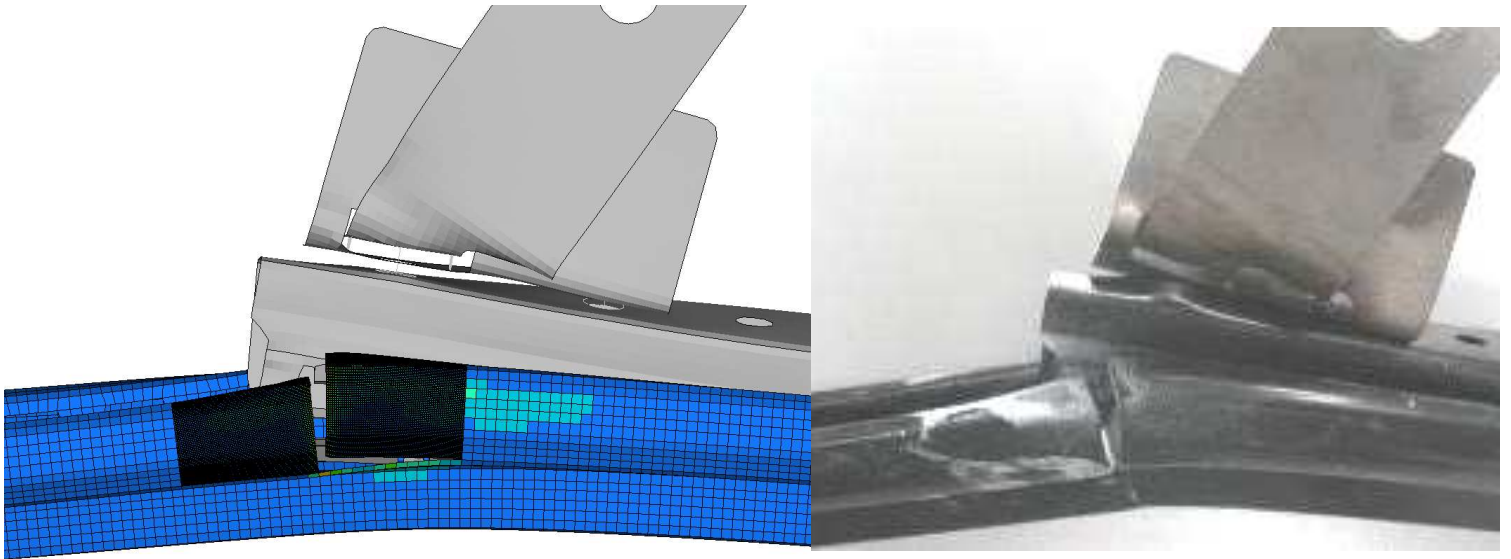
Different mesh sizes have been tested (see picture 11) on patch part, the last one provides a fracture accuracy of 3.7% with the physical test average. This size will be used in the validation

By comparing the results with and without patch, we can conclude that the patch has no influence on the global product stiffness.



Picture 11 Comparison between different patch mesh sizes

Prediction of failure on high strength steel in seat mechanisms simulation



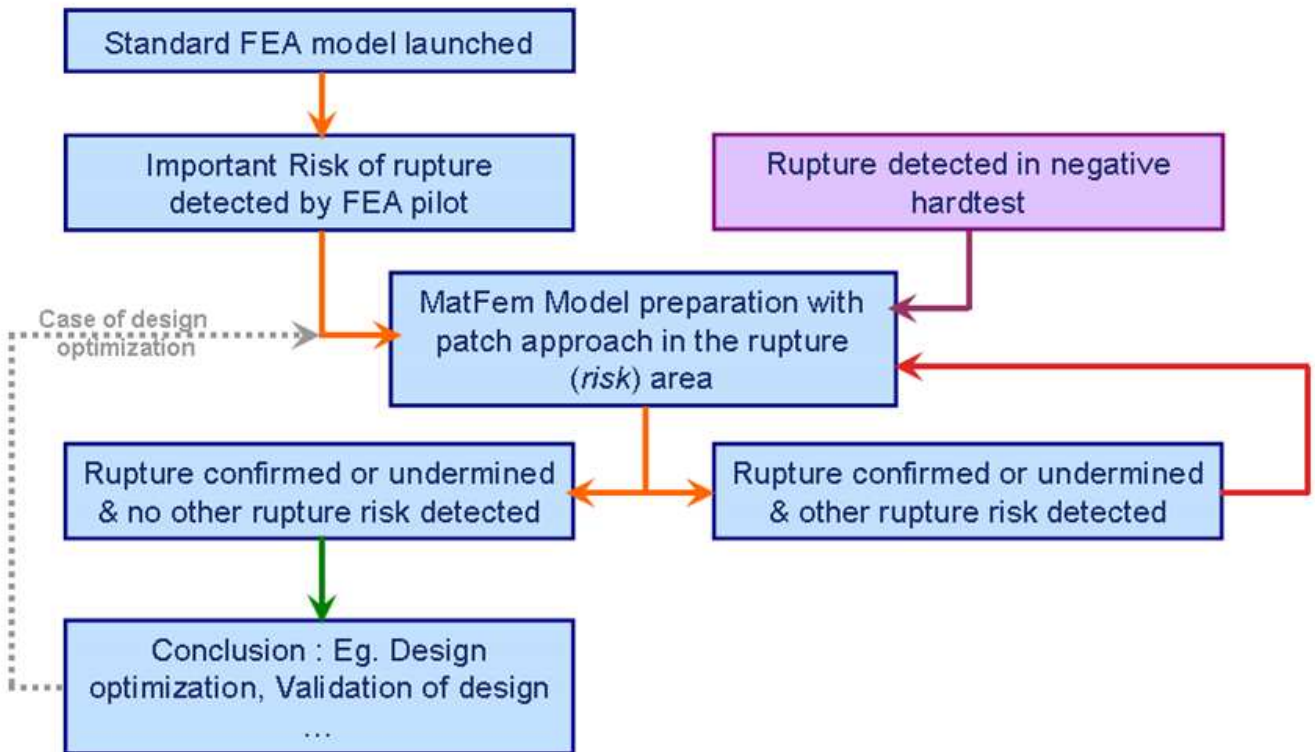
Picture 12 Comparison between FEA CrachFem + patch and hardtest result

The picture 12 shows the rupture identification done by the coupling CrachFem with Ls-Dyna. We can observe that the failure is almost similar than in the physical test. Localization, ultimate strength and propagation of the rupture are validated on this case.

5) Work flow strategy

CrachFem is a very useful tool in term of product optimization. But this solution has the drawback to need more resources in term of CPU time, modeling time and CrachFem licenses. So CrachFem solution can not, for the moment, be defined as a Faurecia *standard* FEA tool for all jobs.

The strategy chosen by Faurecia for the CrachFem tool usage is defined in the next diagram.



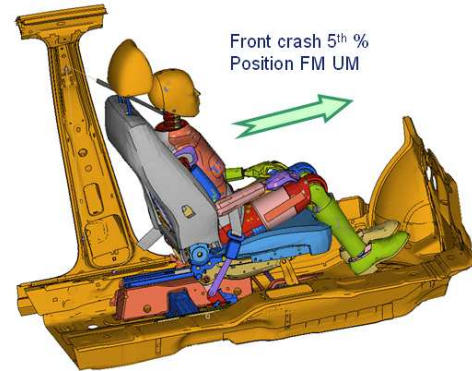
Picture 13 CrachFem workflow diagram

6) Validation on complete seat Crash

Many validations of CrachFem strategy have been performed on sub-models and on complete seat tests. One example of this application is shown on the next pictures (pictures 14, 15, 16)

The presented case is a front crash on complete seat with a 5th percentile dummy. First design (called *design A*) has led to a rupture in track part.

An optimization phase has enabled to define a new design (called *design B*).



Design A : Rupture of the female profile



Design B : No Rupture

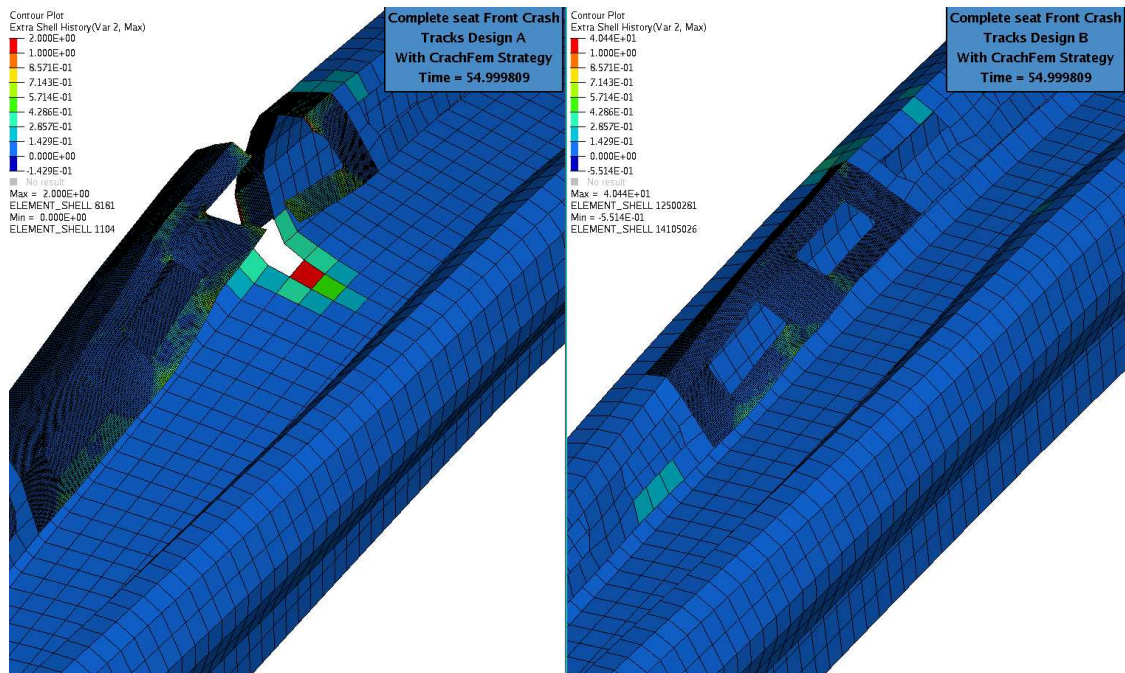


As we can observe on the picture 15, the design evolution has improved the behavior of the tracks during the crash. Now no rupture is detected in physical validation test.

On picture 16, the same comparison is done numerically with the CrachFem strategy presented in this paper.

The conclusion of the design evolution is completely similar between physical and CrachFem numerical approaches.

Prediction of failure on high strength steel in seat mechanisms simulation



7) Prospects

a) On going actions

For few years, Faurecia takes into account in its simulation to forming process history. The process will have an impact on the product mechanical properties. Currently the hardening and the thickness reduction impacts are well represented but nothing is done in term of damage.

Tomorrow CrachFem criteria will be used in the forming process simulation. Rupture criteria values at the end of the process phase will be mapped on crash simulation. With this method the crash model will take into account the "damage" undergone during forming process.

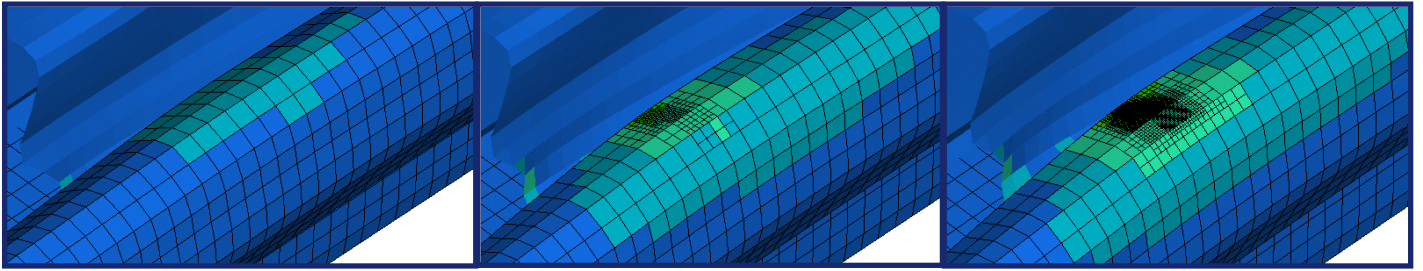
Obviously it's not real damage variable which is a complex phenomenon with mechanical properties changing. Here only "failure risk" history of each element could be used.

b) Future actions

Patch approach is a good compromise between computation time and accuracy on fracture evaluation. But the drawbacks are a more important modeling time and the need to have previously identified the area of rupture.

The next step, under investigation in Faurecia, is to keep this mesh size approach but in an automatic way. The aim is to reduce locally the mesh size in the wished area.

Ls-Dyna offers the possibility to use, on 3D shells, a mesh adaptation by elements splitting "method H-adaptative". The local remeshing is based on shell thinning parameter defined by the user. A complete study on remeshing parameters will be necessary to keep a good compromise between computation time and fracture identification accuracy.



8) Conclusion

As we have illustrated in this paper the rupture is a key topic for Faurecia FEA strategy. With CrachFem tool the design optimization becomes more efficient.

The sub model study has allowed us to define strategy in the CrachFem usage which keeps a correct reactivity of the FEA Tool. The patch approach permits to define correctly the local strain behavior and in this way improve the fracture identification.

Many complete seat validations have proved the robustness of this failure criteria solution. The evolution design example illustrates well the need in term of rupture detection and CrachFem has well answered expectations.

The future work on this topic will continue to improve accuracy and efficiency of the rupture identification by numerical approach.