The application of the damage & fracture material model to crashworthiness evaluations for Aluminum cars

The Improvement of the damage and fracture criterion of MAT81 : MAT81_ORTHO

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ABSTRACT

In an evaluation of crashworthiness for the cars that are made of aluminum alloys, the evaluations that consider a fracture phenomenon come to be needed because conventional aluminum alloys have low fracture strain (10 - 20%). Since an original damage & fracture material model of LS-DYNA, namely MAT_PLASTICITY_WITH _DAMAGE: MAT81 has a damage & fracture characteristic in case of compressive strain state, real collision phenomena can not be simulated in some cases. Therefore, we reviewed the damage & fracture criterion of this material model.

We newly introduced some sort of a damage & fracture criterion into the MAT81 of LS-DYNA V960 in later revision and performed crashworthiness evaluations for an aluminum car using this improved damage & fracture model. This criterion has non-damage & non-fracture characteristic in compressive strain state and it is known as "Orthogonal an-isotropic (Orthotropic) damage & fracture model".

INTRODUCTION – the feature of MAT81

This material model has ISOTROPIC damage & fracture characteristic shown in Fig.1 - 2. Its uni-axial stress-strain curve is completely symmetrical about an origin. Damage (material softening) and fracture occur in tensional and compressive regions. The fracture judgment is done by equivalent plastic strain.

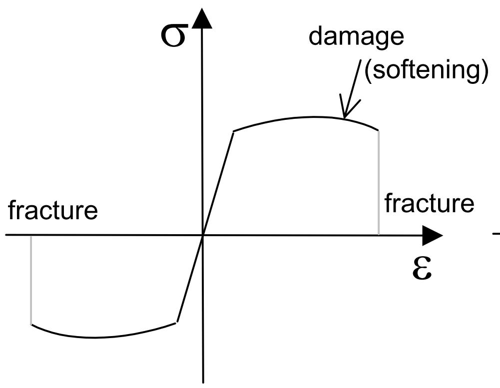


Fig.1 The damage characteristic

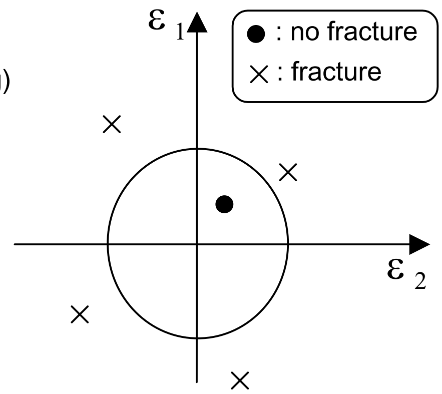


Fig.2 The fracture criterion

Expected Responses in case using MAT81

In case of pure compressive or bending condition, we thought that some wrong responses were expected for ductile material like aluminums as Fig.3, because of the compressive fracture characteristic of MAT81.

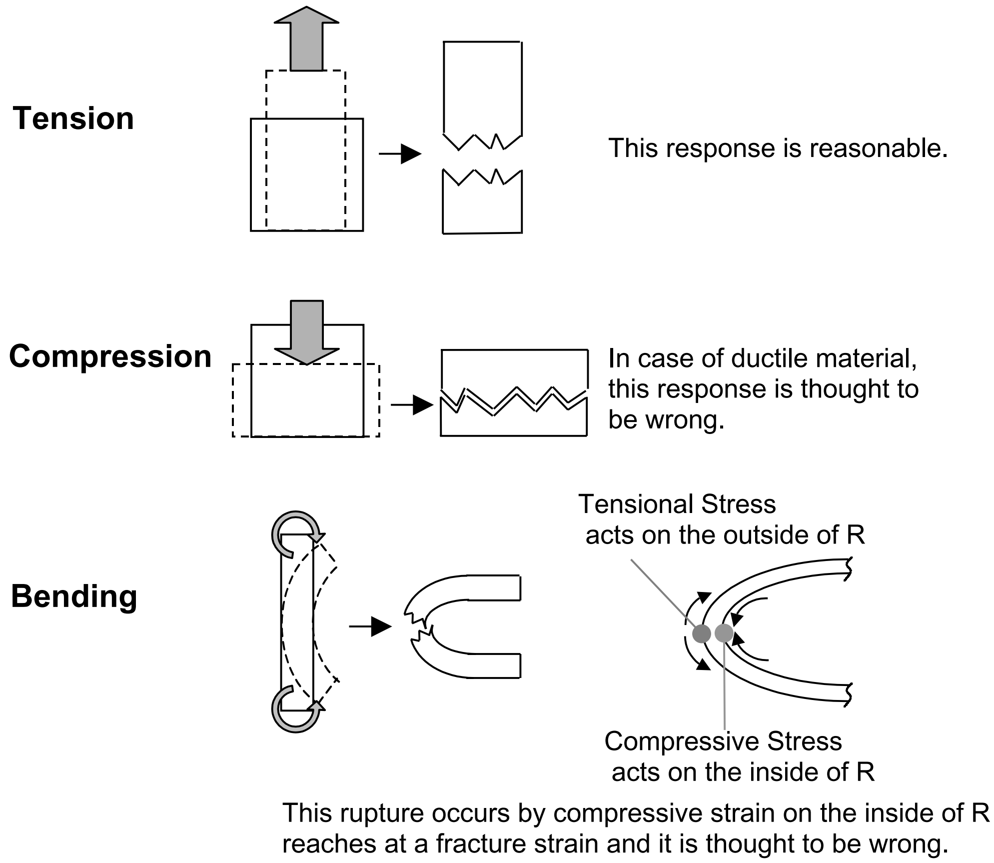


Fig.3 Expected responses in case using MAT81

Computational results using MAT81

Using MAT81 and type16 shell element, we examined some strength simulations about axial compression and bending tests (Fig.5 - 8), but we couldn't get good agreement with the test results. Material properties that were used in these simulations were measured from uni-axial tensile tests. Specimens in a coupon shape were cut from actual parts and their strains were measured by optical (Fig.4).

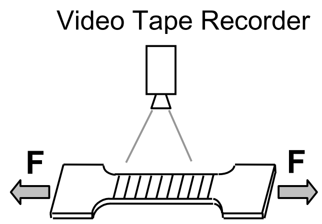


Fig.4 Uni-axial tensile test

In those cases (Fig.5 - 8), the compressive strain that occurred on the inside of R caused early fracture and early element rupture. Fig.6 shows a stress-strain history of a certain element that ruptured at early time. It shows that the compressive strain on the inside of the R firstly reached at a fracture strain and last, the tensional strain on the outside of the R reached at a fracture strain (see a mark "x" in Fig.6). Therefore, the fracture criterion was satisfied at all integration points and the element ruptured.

<CASE1>

An axial compression test of a straight member with octagonal section

Original MAT81 TEST RESULT

Fig.5 The deformation comparison (MAT81)

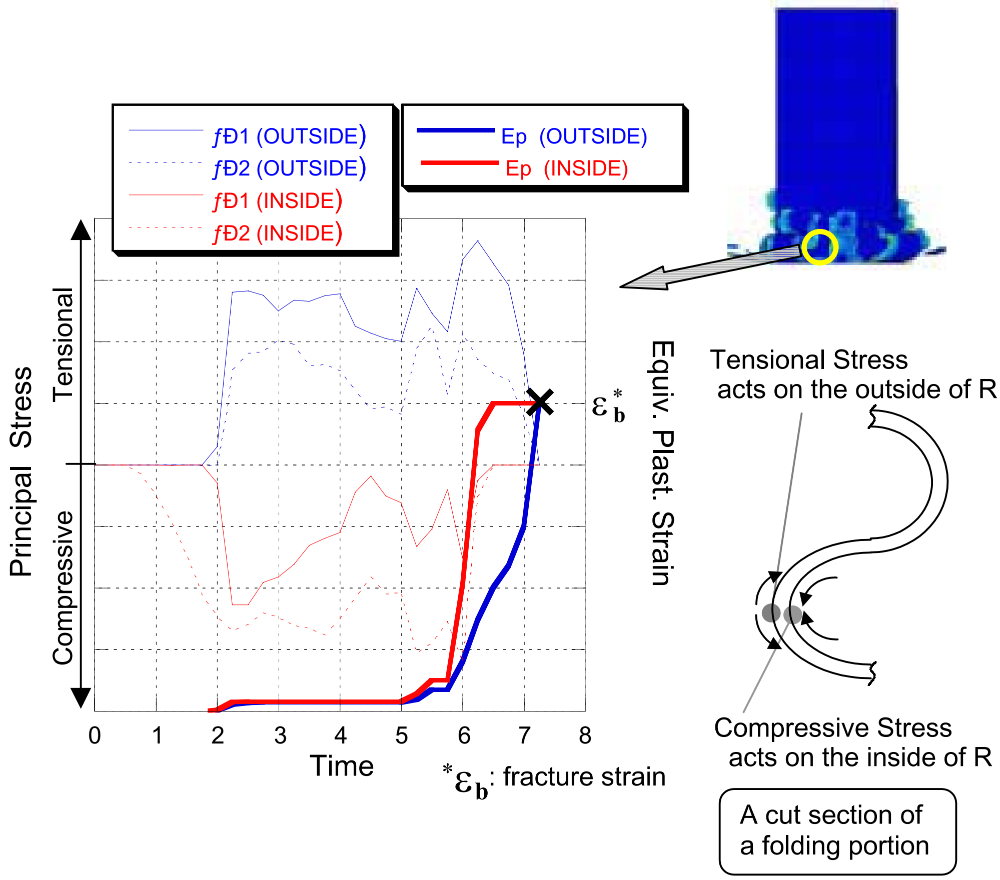
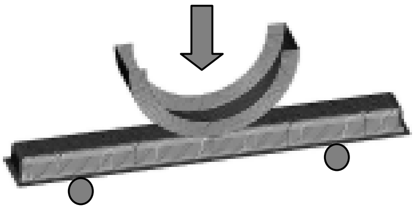


Fig.6 The stress-strain state of the ruptured element

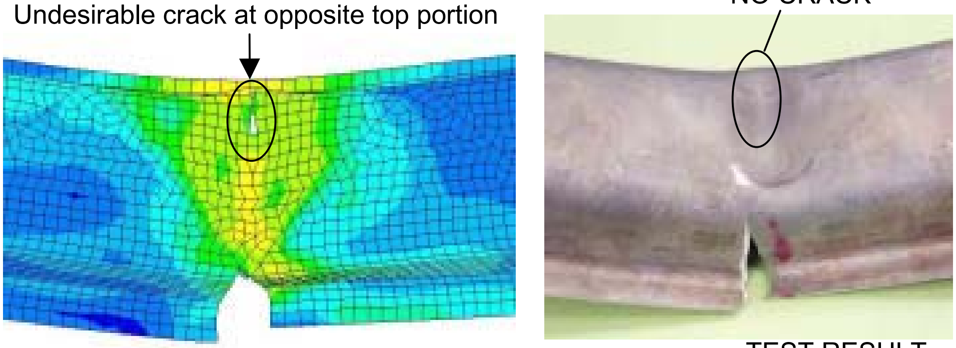
<CASE2 >

A 3 points bending test of a straight member



Undesirable crack at opposite top portion

NO CRACK



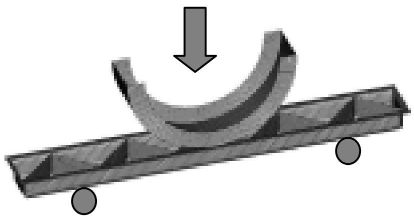
Original MAT81

TEST RESULT

Fig.7 The deformation comparison (MAT81)

<CASE3>

An upside down case of the case2



Undesirable cracks at each side

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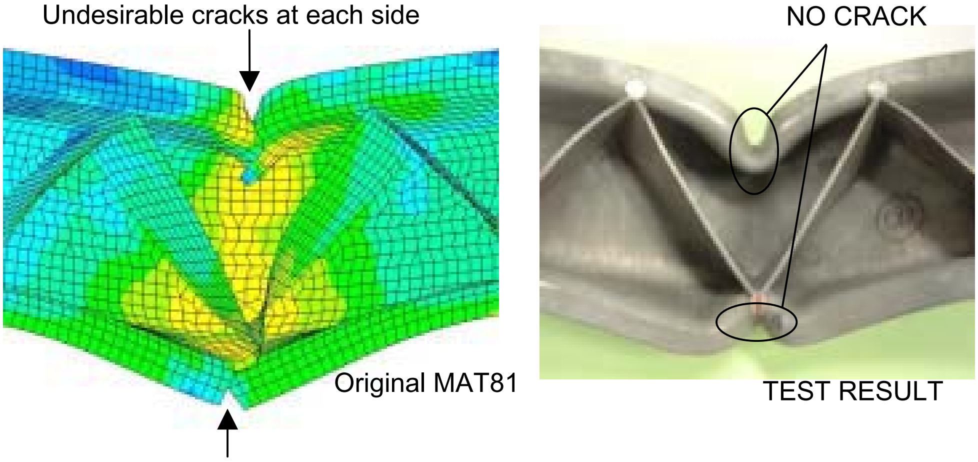


Original MAT81

TEST RESULT

Fig.8 The deformation comparison (MAT81)

Approach

From those results, we thought that compressive strain makes wrong responses for ducktail failure in case using ISOTROPIC fracture criterion. Therefore, we invoked "Orthotropic damage & fracture model" to exclude compressive strain from the fracture criterion (Fig.9).

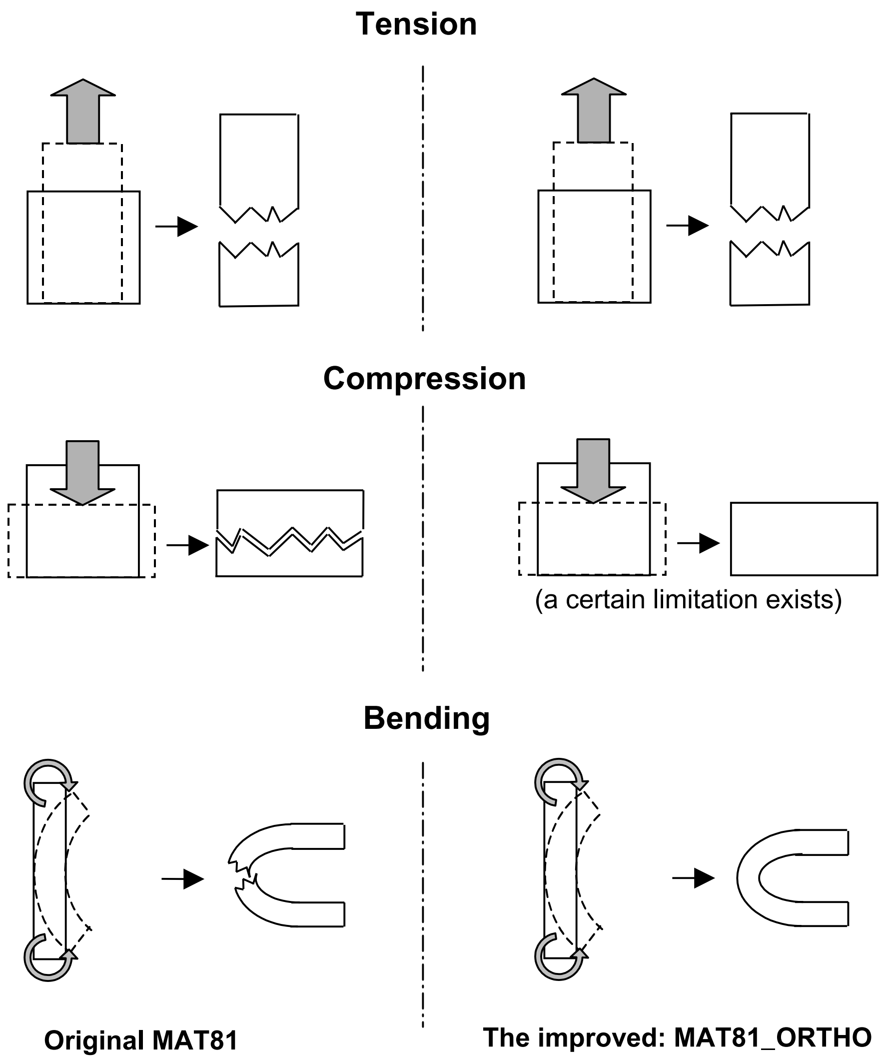


Fig.9 The Approach

The feature of *MAT_PLASTICITY_WITH_DAMAGE_ORTHO – MAT81_ORTHO

(1) An element ruptures, if one of principal strains (Fig.10) reaches at a tensional fracture strain (If principal strain is compressive one, it is excluded from fracture judgment). Fracture is judged at each integration point.

(2) In compressive region, material damage (softening) never occurs.

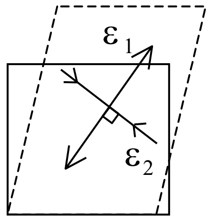


Fig.10 Principal Strains

(3) Rupture timing is controllable. The number of integration points to judge fracture is optional (from 1 up to all integration points).

(4) From (1), if an element is forced excessive uni-axial compression, the principal strain that is perpendicular to the axis may reach at a fracture strain (Fig.11) because of the constant volume requirement in plastic deformation.
In the case, the element is deleted as rupture.
This is a limitation of Orthotropic Model.

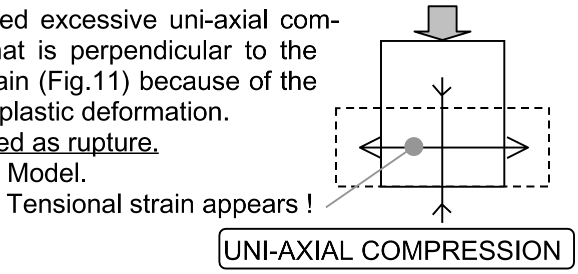


Fig.11 A limitation of Orthotropic Model

The characteristics of MAT81_ORTHO are shown in Fig.12 - 13 and Table 1.

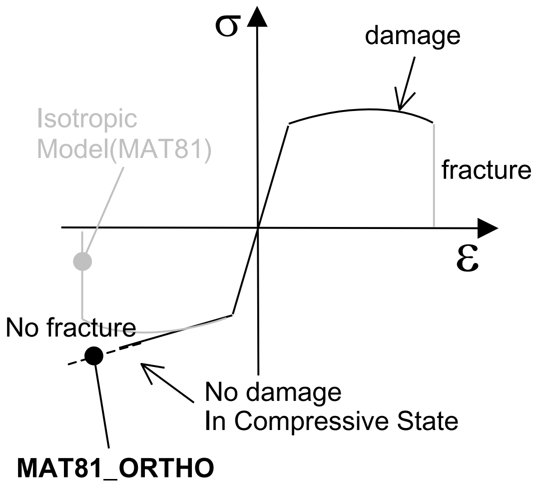


Fig.12 The damage characteristic

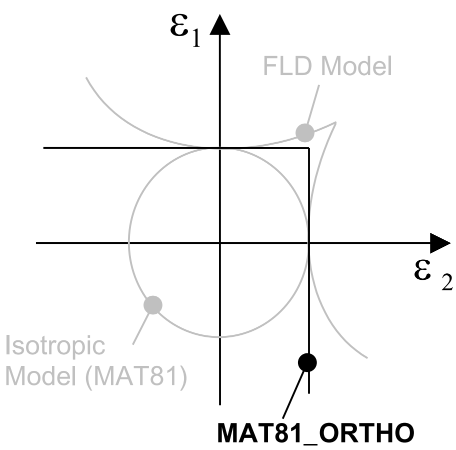


Fig.13 The fracture criterion

Table 1 Summary of damage & fracture models

Material Model	Strains to be considered	Tensional Strain State		Compressive Strain State	
		Damage (softening)	Fracture	Damage (softening)	Fracture
MAT81	Equiv. Plastic Strain ε_p	✓	✓	✓	✓
The improved (MAT81_ORTHO)	Princ. Plastic Strains(ε_1, ε_2)	✓	✓	-	-

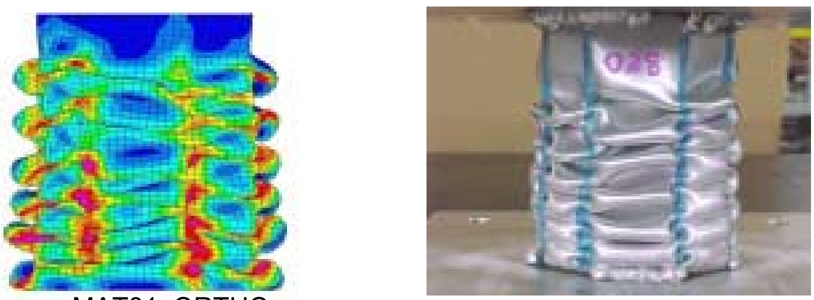
- : No Consideration

The Application to strength evaluations

We evaluated the same examples by using MAT81_ORTHO. In these cases, the number of integration points for fracture judgment is all (blank field means "ALL") and type16 shell element was also used. The results had acceptable correlation with the test results.

CASE1: An axial compression test of a straight member with octagonal section

Fig.14 - 16 show that the results of the axial compression simulation. Using MAT81 with ORTHO option, we managed to simulate the folding mode. Fig.15 shows a comparison of stress-strain history of the element that ruptured at early time in case using original MAT81.
It shows that the compressive strain on the inside of the R reached at a fracture strain (see a mark "x" in Fig.15), but the improved fracture criterion ignored it, then this element wasn't deleted as rupture.



MAT81_ORTHO TEST RESULT

Fig.14 The deformation comparison (MAT81_ORTHO)

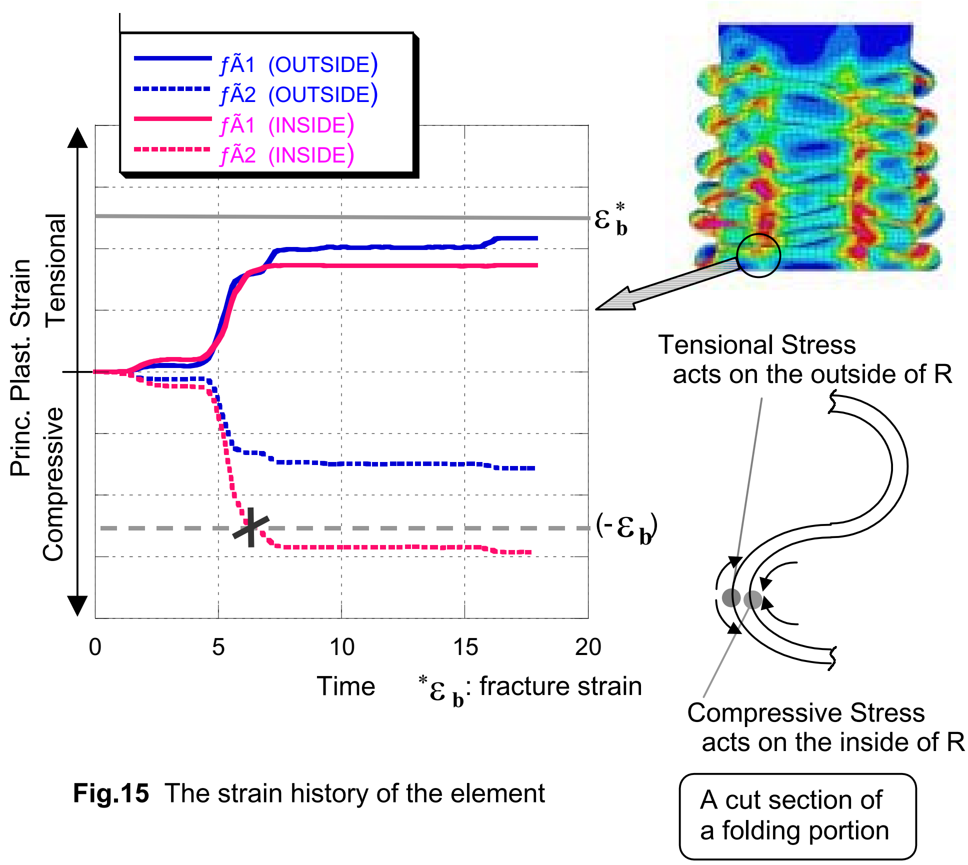


Fig.15 The strain history of the element

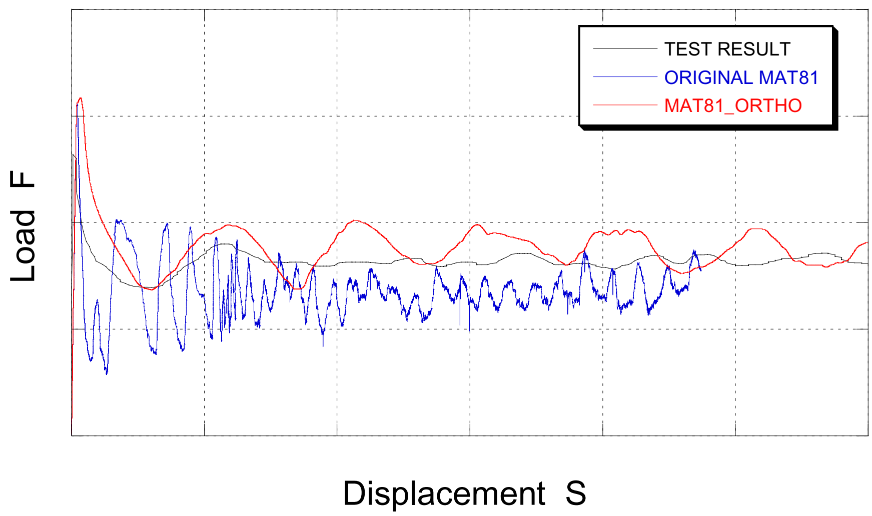


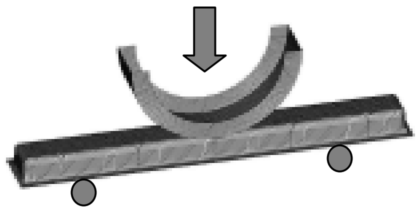
Fig 16 The load-displacement comparison

Fig.16 shows a comparison of the load-displacement curves. The result that used ORTHO option has acceptable correlation with the test result.

CASE2: A 3 points bending test of a straight member

Fig.17-18 show the results of the 3 points bending simulation. The member is the same as the case1 that used original MAT81. In case using ORTHO option, we managed to simulate the crack that was occurred at sidewall. The crack in the ceiling that occurred in case using original MAT81 (Fig.7) disappeared.

Fig.18 shows a comparison of the load-displacement curves. The result has good correlation with the test result.



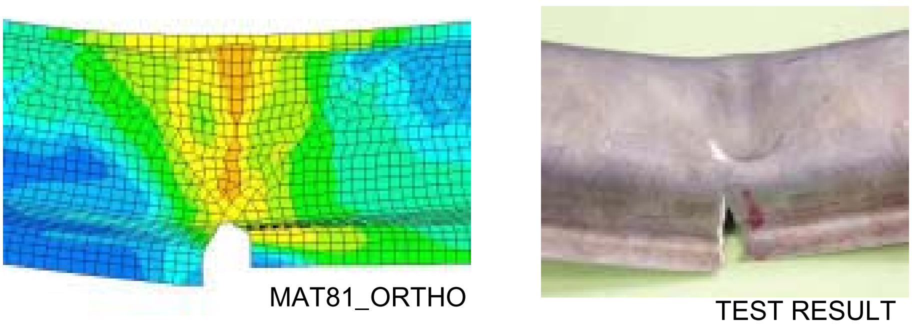


Fig.17 The deformation comparison (MAT81_ORTHO)

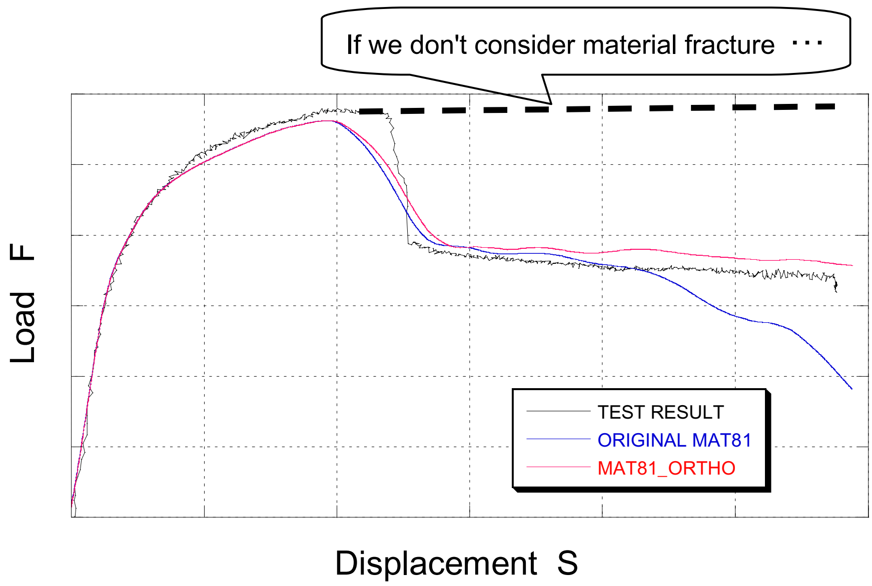
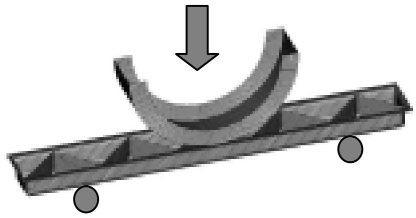


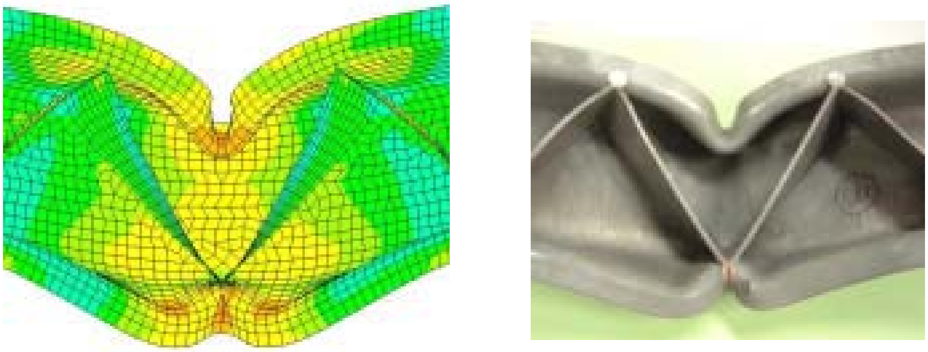
Fig.18 A comparison of the load-displacement curves

CASE3: An upside down case of the case2

Fig.19-20 show the results of the upside down case of the case2. Using ORTHO option, we managed to simulate the folding mode of the flanges. The cracks at each side of the member that occurred in case using original MAT81 (Fig.8) disappeared.

Fig.20 shows a comparison of the load-displacement curves. The result has also good correlation with the test result.





MAT81_ORTHO TEST RESULT

Fig.19 The deformation comparison (MAT81_ORTHO)

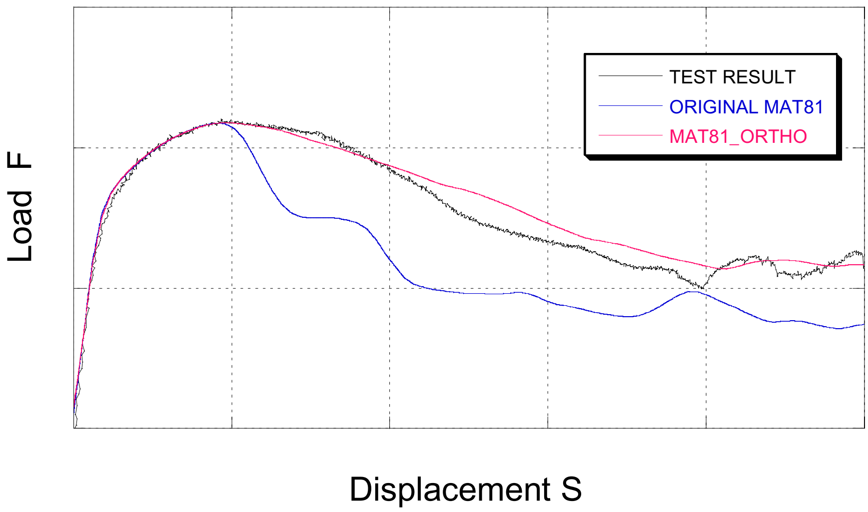


Fig.20 A comparison of the load-displacement curves

The Application to crashworthiness evaluations for Aluminum cars

We performed both a test and a simulation in consideration of side impact collision to estimate performances of a car-body made by aluminum alloys.

In this test, the car body was cut in half and the cutting edges of cross members were attached in a vertical fixed wall through load-cells to measure transmitted forces. A MDB was equipped with a hydraulic power cylinder to load force on the car body. The test was done by quasi-static condition.

Fig.21 The test result

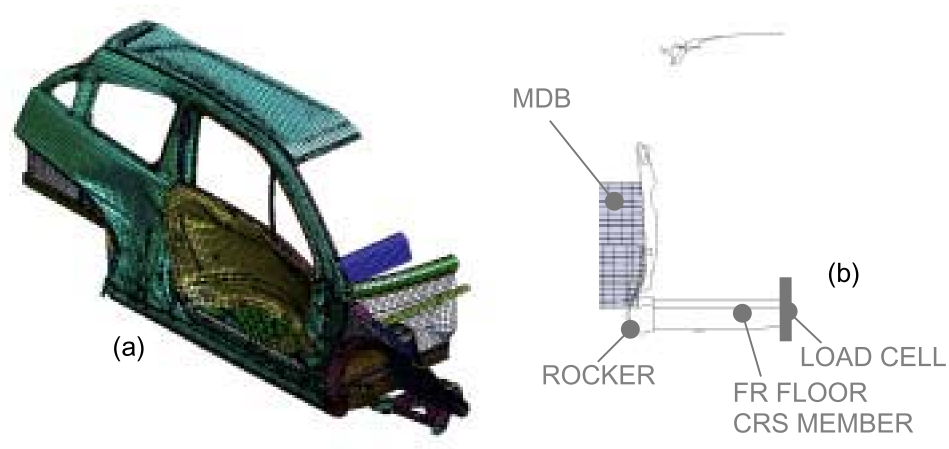


Fig.22 the 1/2 cut body FE-model of the car

Fig.21 shows the deformation of the body after the test. Fig.22 shows the model (a) and its cut section at a floor cross member (b). Fig.23 shows a comparison of the load-displacement curves about the transmitted force of the floor cross member.

The each result by original MAT81 or ORTHO option has good agreements with the test result. From the results, in both cases, it is found that the applied external loads from the MDB are much the same between the simulation and the test.

Fig 24 shows the deformation of the body that was viewed from inside of the cabin. A crack occurred at a B-Pillar flange by an end of an impact beam attached to a door.

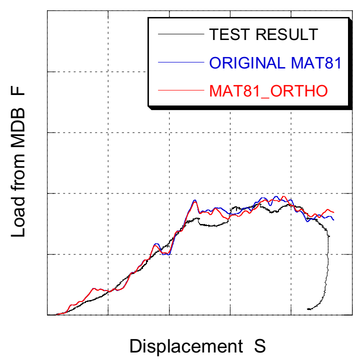


Fig.23 The load-displacement curves

Fig.25-(a) shows the computational result that used ORTHO option. The initial crack at the B-Pillar's flange managed to be simulated, but propagation of the crack (it may be concern in Zipper effect) couldn't be simulated. Fig.25-(b) shows the computational result that used original MAT81. In the case, a wrong crack occurred below the actual one. We don't describe a precise explanation about that, but the reason of occurrence of the wrong crack is the same as we already mentioned.
That is, the crack occurred by compressive strain on the inside of R.

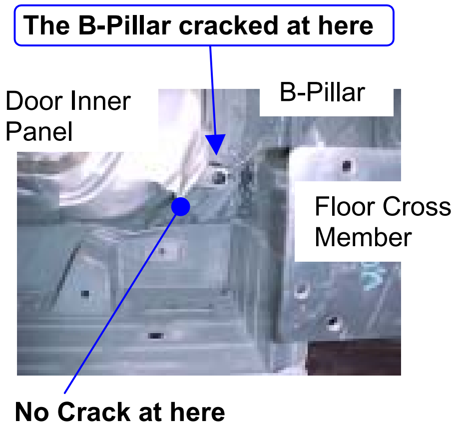


Fig.24 The test result

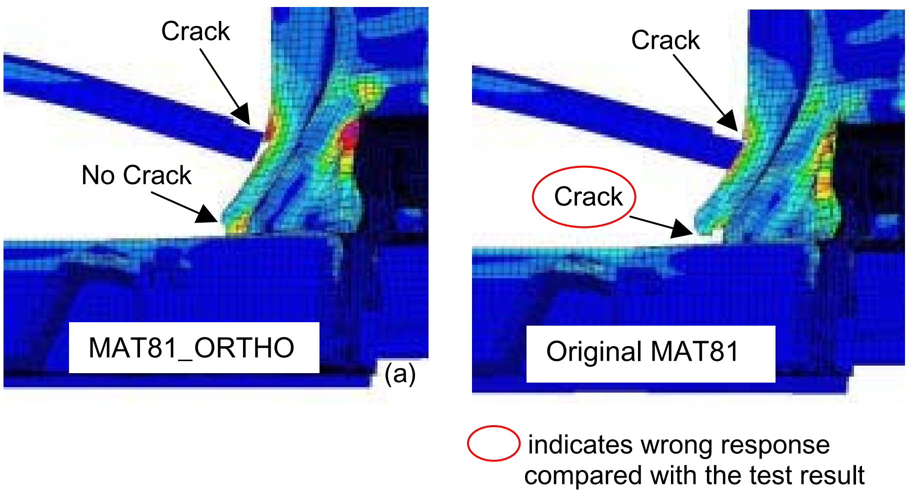


Fig.25 The computational results

Conclusion

(1) Using MAT81 with ORTHO option, crashworthiness evaluations for aluminum parts in consideration of material damage & fracture phenomenon come into action.

(2) In case of the application to the crashworthiness evaluation of our experimental aluminum car, MAT81 with ORTHO option had satisfactory performances.

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