RESIDUAL STRENGTH OF THE CARBON FIBER PANEL WITH DELAMINATION

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Abstract: *Carbon fiber reinforced materials are getting widely spread. But at present time method of the calculation of impact residual strength for carbon fiber parts is poorly developed. Especially this method is underdeveloped in case of the delaminated composite parts. Residual strength is very essential for any project where the composite material parts are used. The possibility to estimate the value of residual strength of the carbon fiber reinforced parts is highlighted in terms of safety for Aerospace structures.*

In this work we propose a method to calculate the carbon fiber panel residual strength of the civil plane wing prototype with respect to delamination progress simultaneously with degradation law of the material properties. This approach has been developed and realized based on ABAQUS software.

All numerical models are presented and the dependence of panel residual strength on the delamination size was shown based on these models.

Keywords: *Composite Materials, residual strength, delamination, Hashin's criteria.*

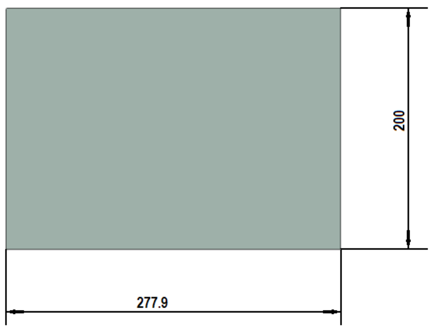
1. Introduction

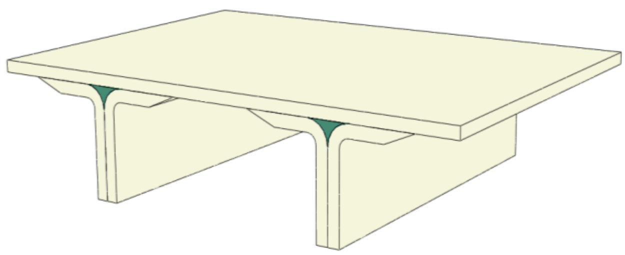
FE analysis is presented in this paper. The carbon fiber panel of the civil plane wing prototype is a research object. The complete description of this object and material properties is shown. Obtained results are presented.

The Objective: To determine residual strength of the specimens without/with delamination due to 90, 140 and 370 Joules energy impact into trim.

2. Finite element model

The object of research is a part carbon fiber panel of the civil plane wing prototype. Figure 1 shows the sketch of the object and it's material properties. (all the dimensions are in mm)





Material Properties				
E_{11}	$E_{22}=E_{33}$	$G_{12}=G_{13}=G_{23}$	ν_{12}	$\nu_{13}=\nu_{23}$
16800	821	446	0.322	0.015

Figure 1 The object of research

Mesh for the part was built using 8-node quadrilateral in-plane general-purpose continuum shell elements, with hourglass control of elements. Meshed part is shown in the Figure 2. Total number of elements: 53 370.

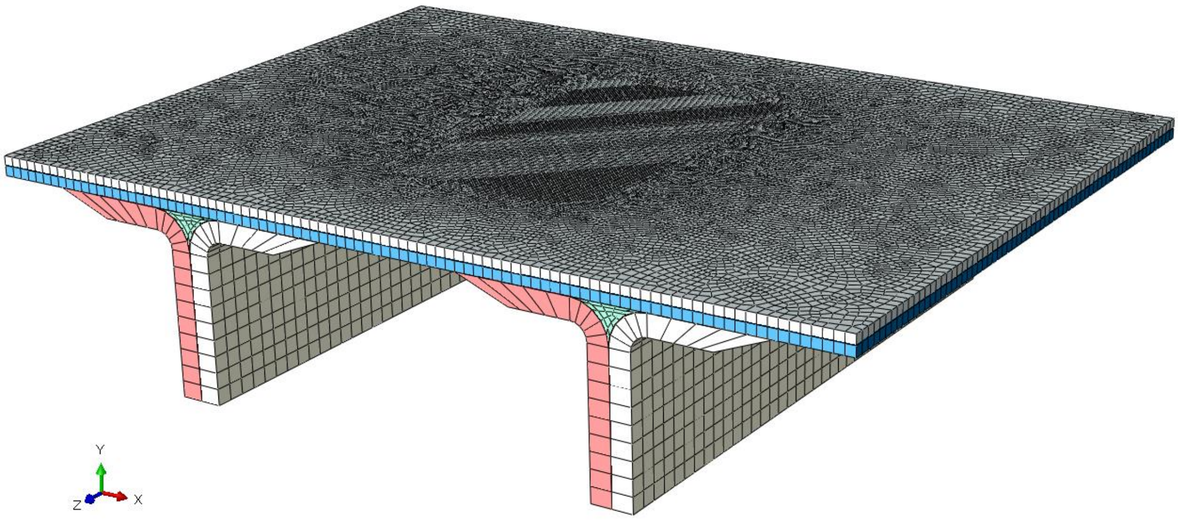


Figure 2 - Mesh

3. Boundary conditions

To get the RF (reaction forces and moments) from the point all BCs were made through center points with the coupling to the surfaces. The compression load was applied to the front edge of the panel from the coupling point. Opposite edge was encased in all degrees of freedom, Figure 3.

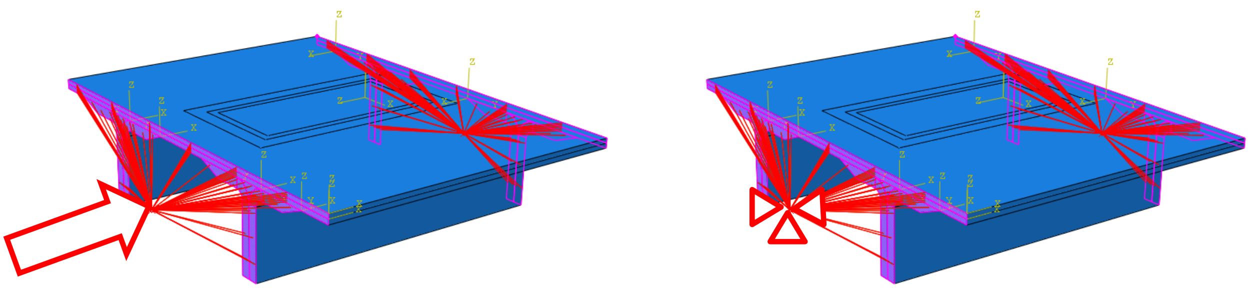


Figure 3 – Boundary conditions

4. Hashin criteria & VCCT modeling in Abaqus/Standard

In Abaqus the damage initiation criteria for fiber-reinforced composites are based on Hashin's theory. These criteria consider four different damage initiation mechanisms: fiber tension, fiber compression, matrix tension, and matrix compression [1, 2].

In order to make the criteria work and the material properties degradation, damage parameters were entered:

	Tensile Strength	Compressive Strength	Shear Strength
Longtitudinal	268	107	11.3
Transverse	8.77	21.6	11.3

In the case to model delamination progress in Abaqus/Standard the VCCT (Virtual Crack Closure Technique) was used. VCCT is based on the assumption that the strain energy released when a crack is extended by a certain amount is the same as the energy required to close the crack by the same amount [1, 3].

VCCT Properties:

Mode I	Mode II	Mode III
0.056	0.32	0.32

From the global model of the panel a local one was built. It has the size 20x20 mm and located in the panel center, Figure 4.

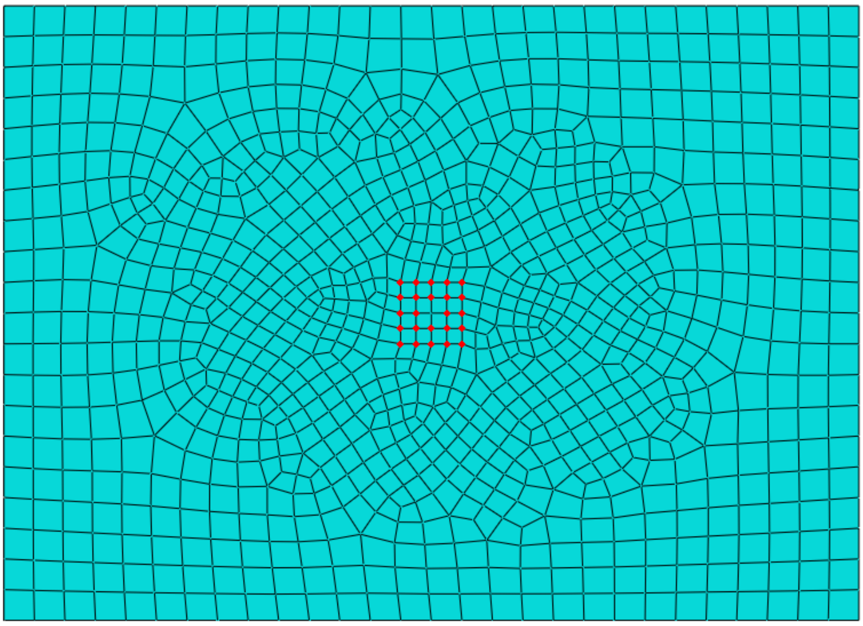


Figure 4 – Delamination area (20x20 mm, delamination- the node not marked red)

Each layer has VCCT interaction. After loading this model we got EFENRRTR (Effective energy release rate ratio) of every layer, Figure 5, Figure 6.

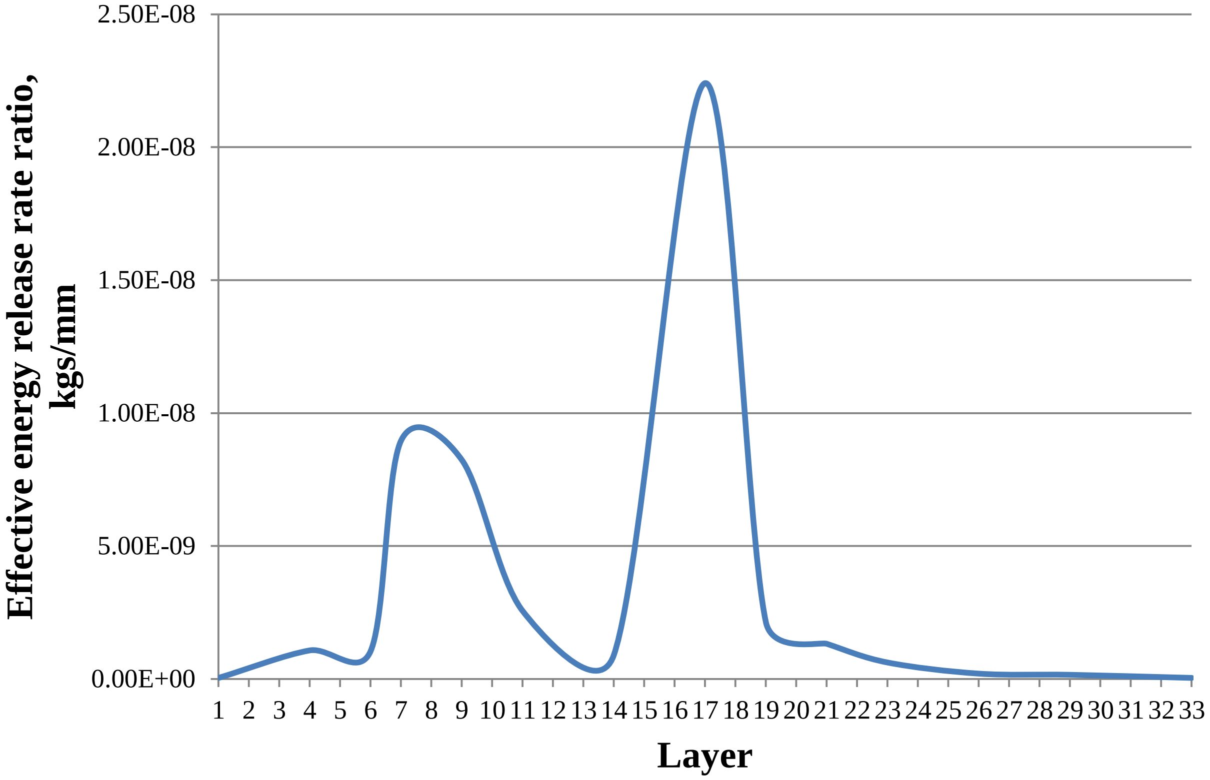


Figure 5 – Plot of ENERRTR

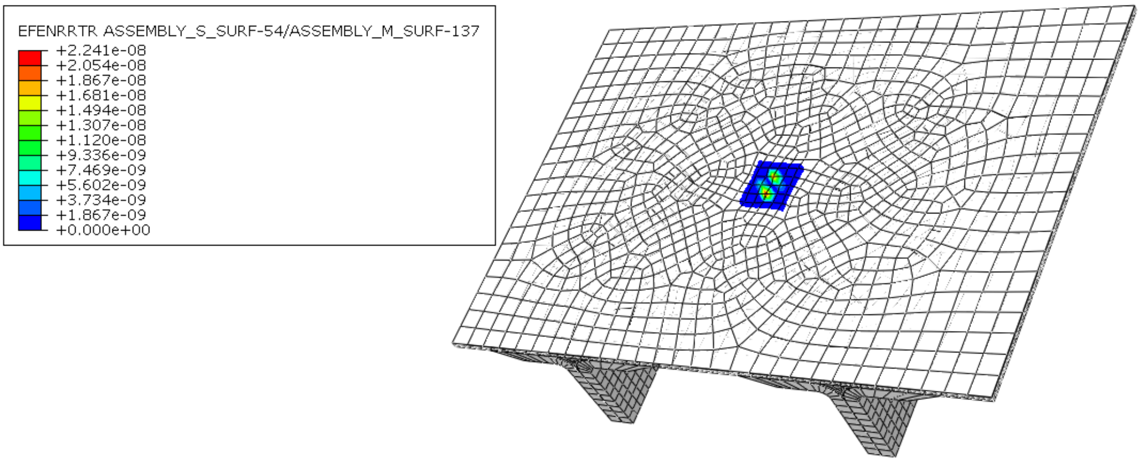


Figure 6 – Maximum of EFENRRTR

Maximum of EFENRRTR is 2.241e-08, this energy is between layers 17 and 18. After we got the value of max of EFENRRTR and the layers from local model we located the declamation in this place in full-sized model.

5. Results

A series of numerical panel using Abaqus were used to demonstrate differences in delamination damage, but generally it can be divided into two parts:

1. Determination of residual strength of the undamaged panel
2. Determination of residual strength of the panel with delaminations.

5.1. Determination of residual strength of the undamaged panel

Initiation of Hashin criteria starts at values U (Displacement) 1.16 mm and RF (Reaction Force) 258 586 kg. Damage initiation begins from the fiber compression mechanism. Stress distribution at this time is shown in Figure 7, 8.

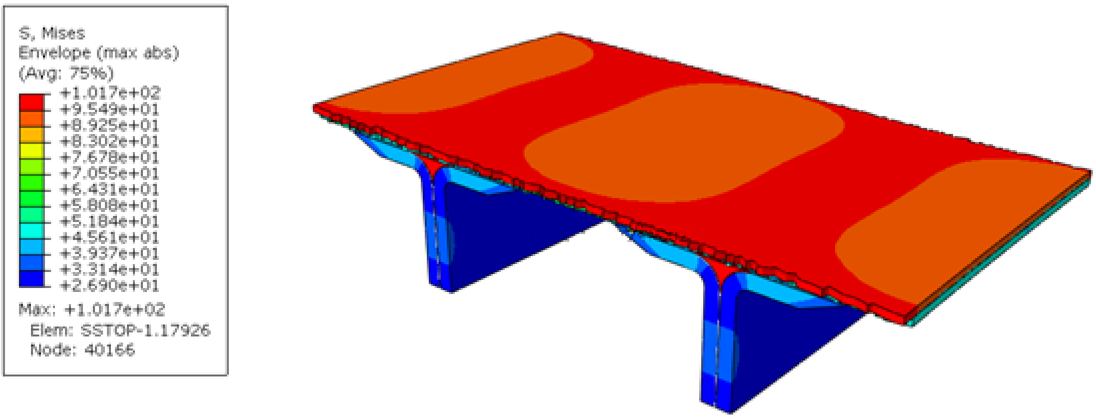


Figure 7 – Stress distribution

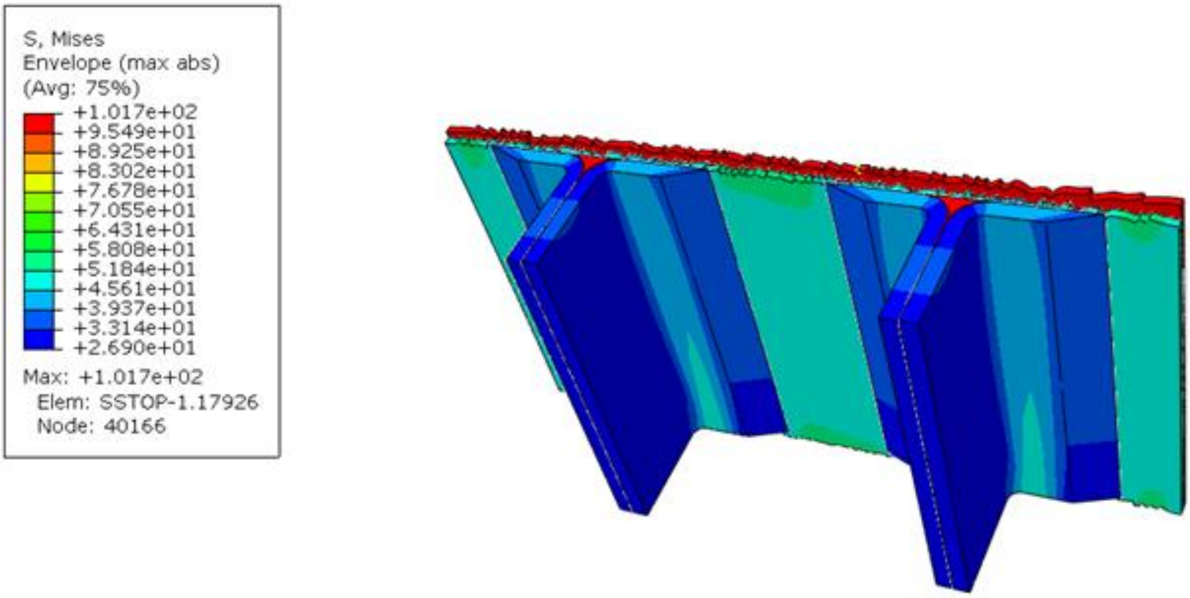


Figure 8 – Stress distribution

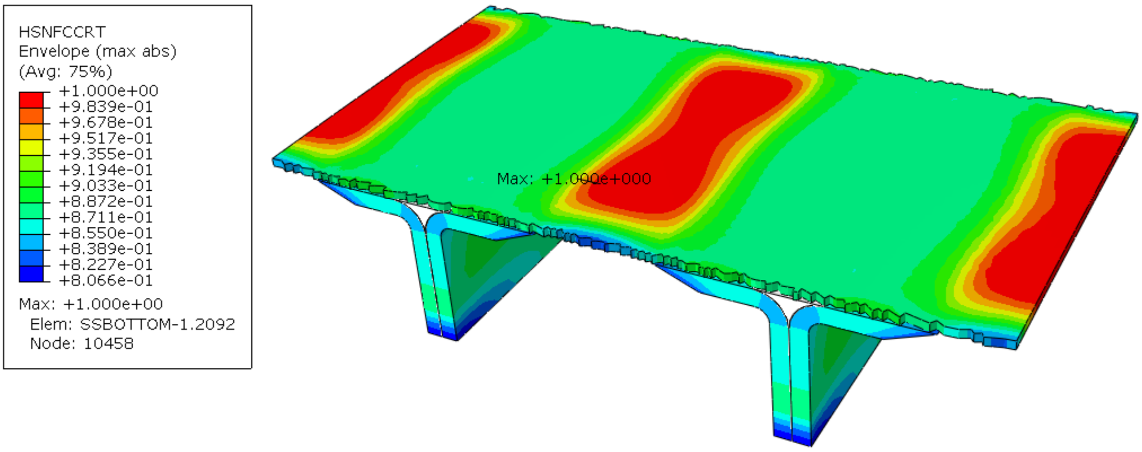


Figure 9 – Hashin criteria initiation

Fiber destruction initiates in layers 2 and 3 (counting from stringer flange) Figure 9 and 10.

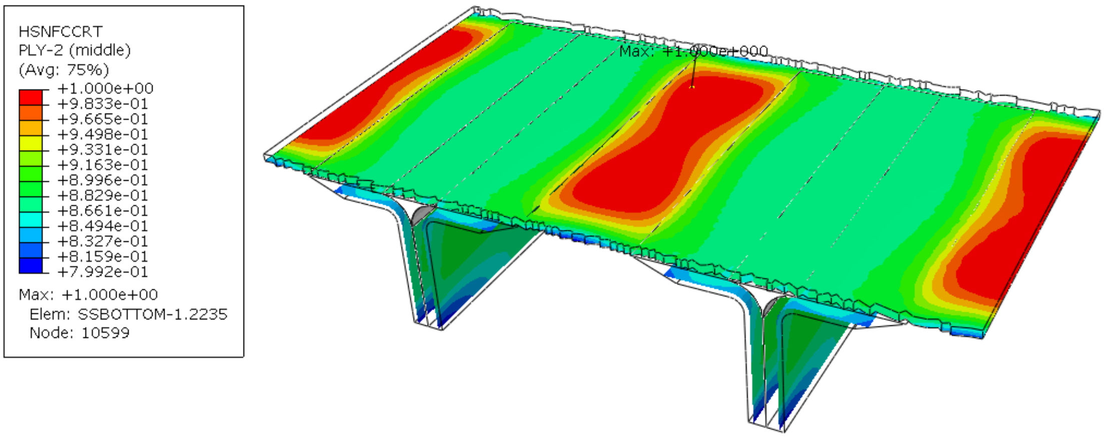


Figure 10 – Ply 2 (0^0)

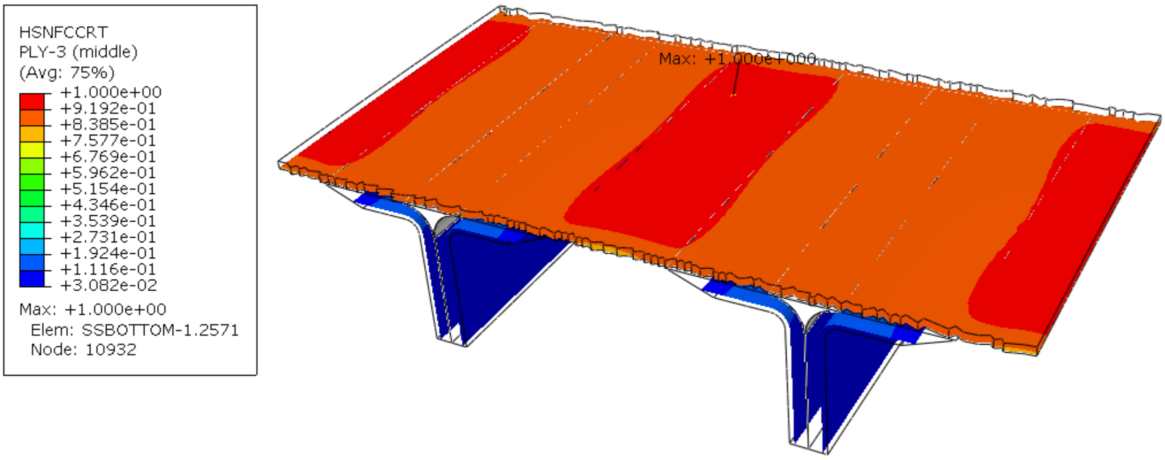


Figure 11 – Ply 3 (-45^0)

The plot shows loading conditions (red line) and the place (blue dot) where Hashin criteria initiate.

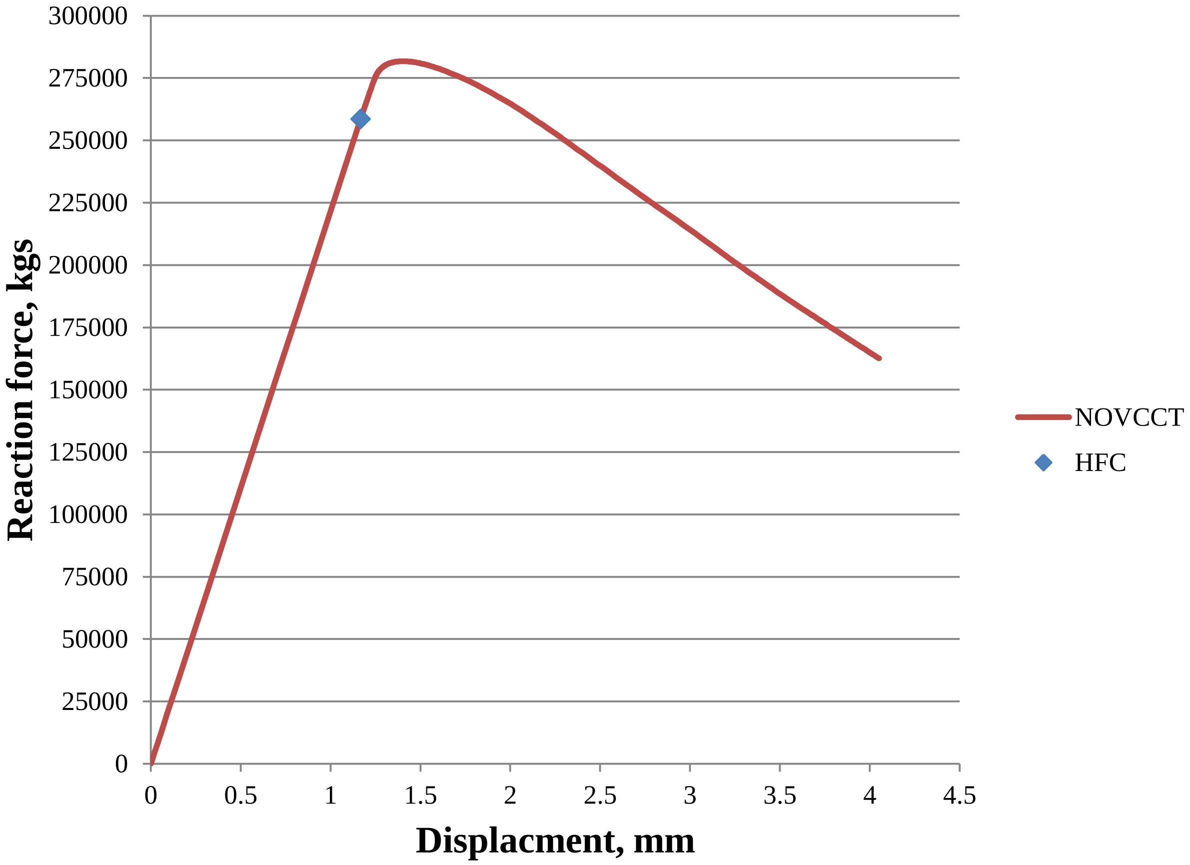


Figure 12 – Panel without delaminations

5.2. Determination of residual strength of the specimens with delamination

Initiation of Hashin criteria start at values U (Displacement) 1.21 mm and RF (Reaction Force) 258 586 kg. Damage initiation begins from the fiber compression mechanism. Stress distribution at this time is shown in Figure 9 and 10.

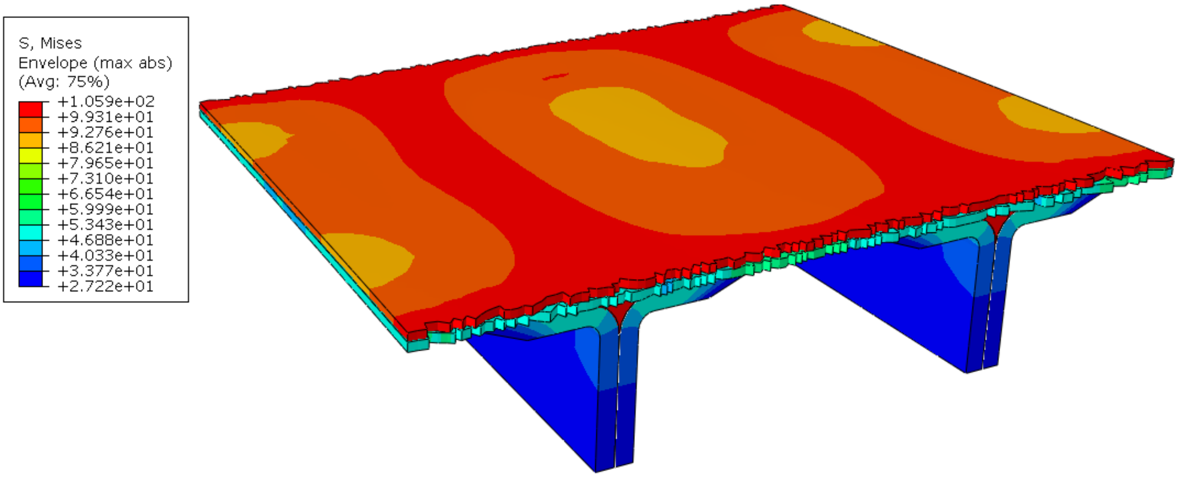


Figure 13 - Stress distribution

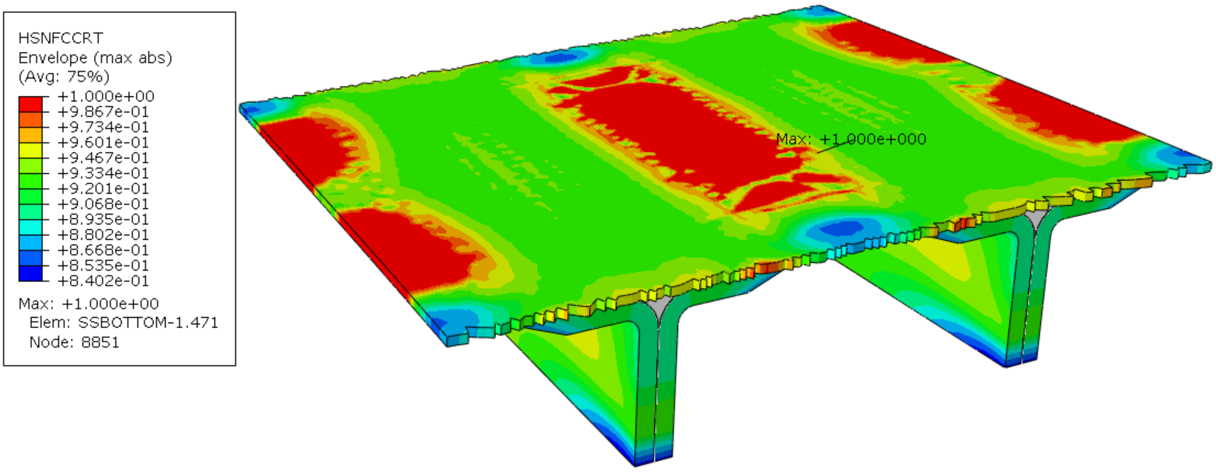


Figure 14 - Stress distribution

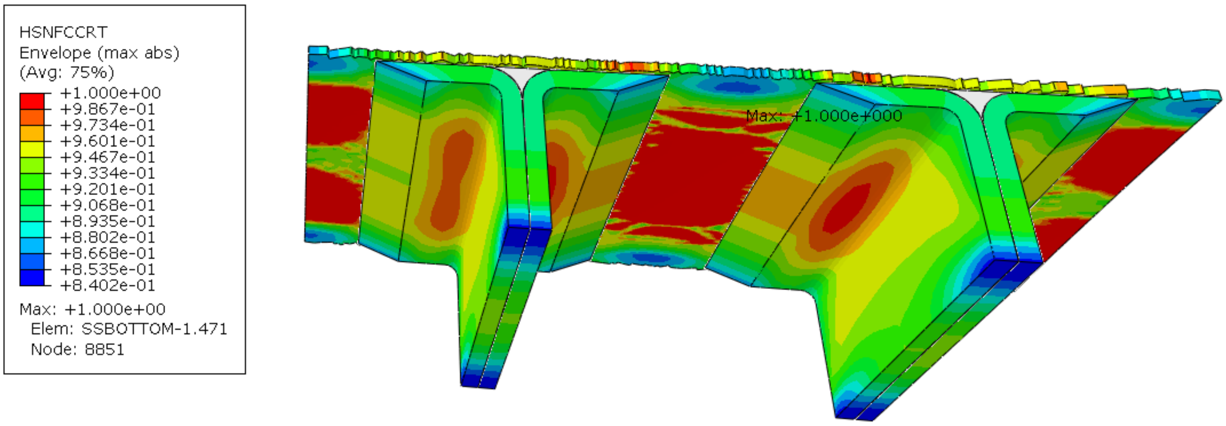


Figure 15 - Stress distribution

Fiber destruction initiates from layers 2, 3, 5, 8, 10, 11, 13, 14, 16 (counting from stringer flange). The place of the damage is shown in the figures below.

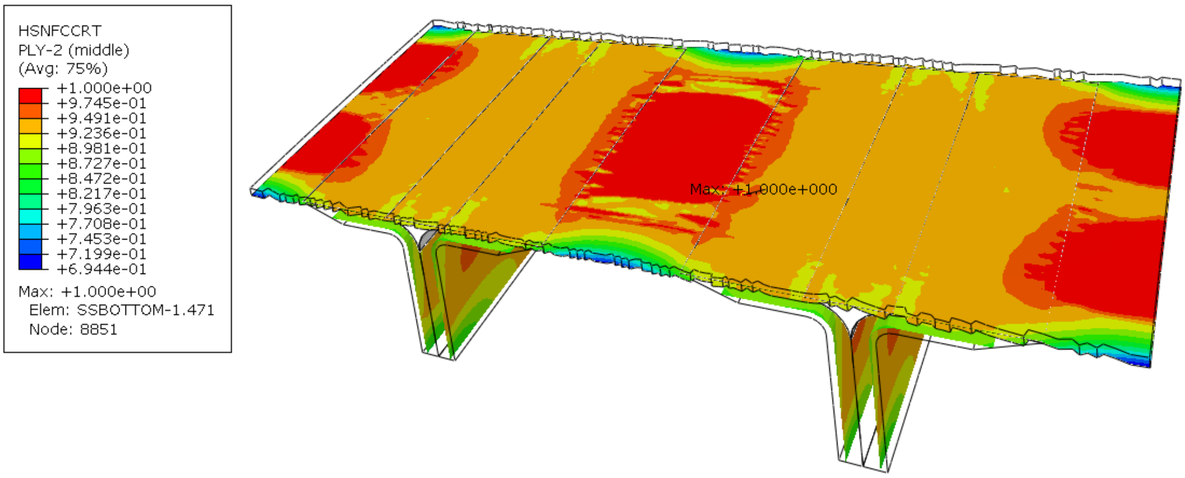


Figure 16 – Ply 2 (0^0)

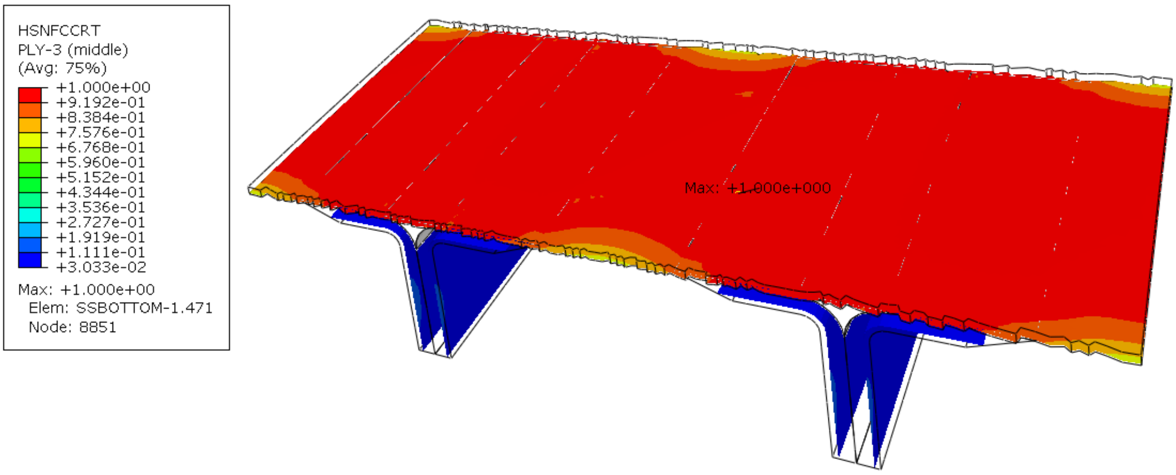


Figure 17 – Ply 3 (-45^0)

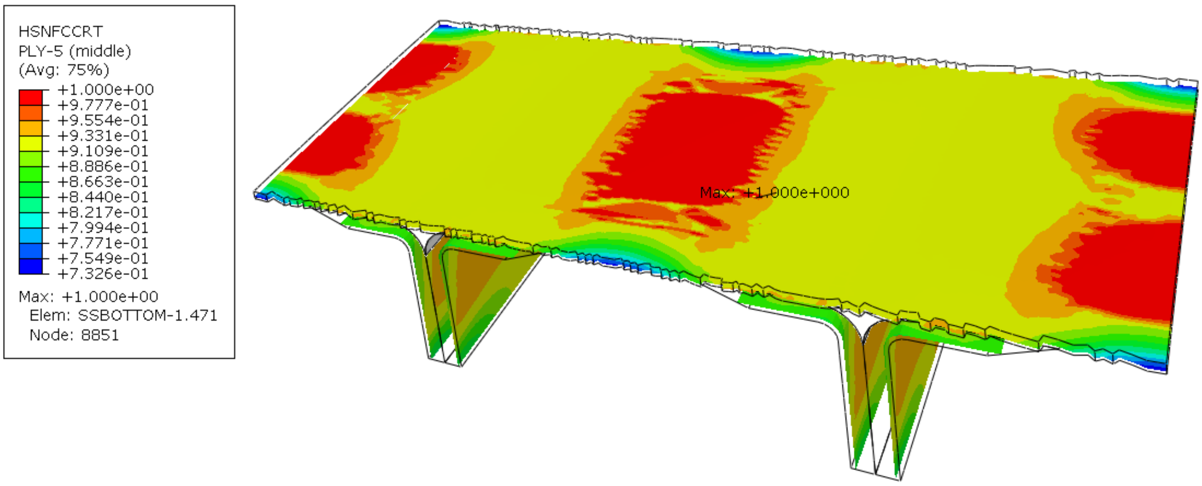


Figure 18 – Ply 5 (0^0)

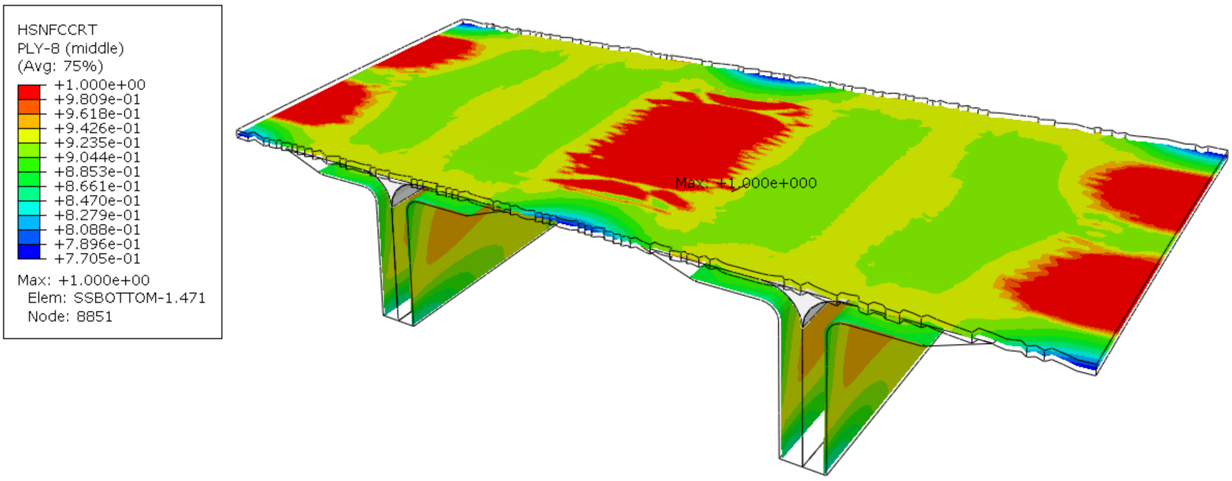


Figure 19 – Ply 8 (0^0)

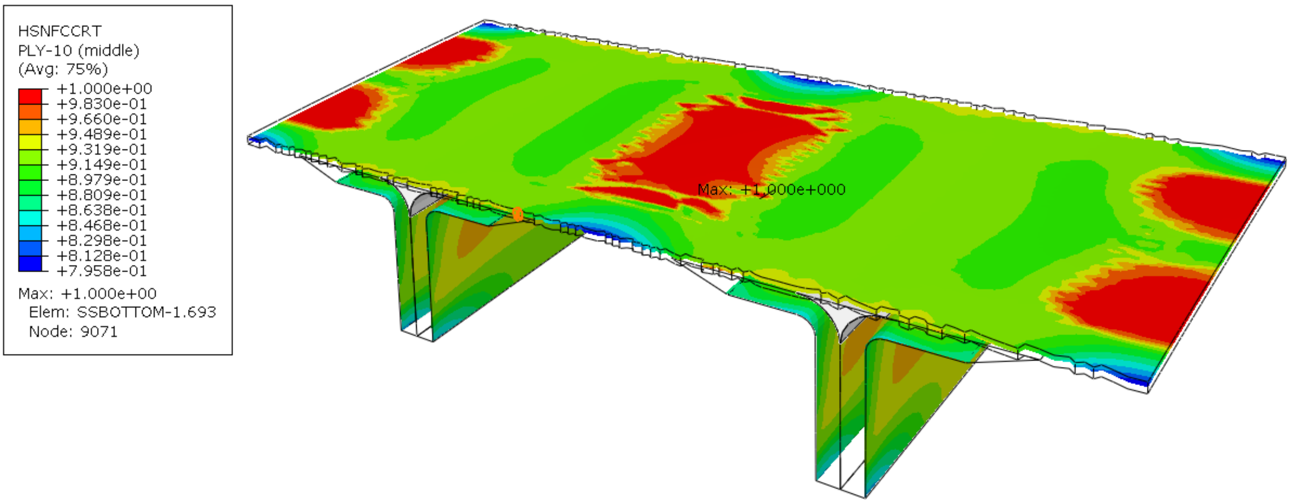


Figure 20 – Ply 10 (0^0)

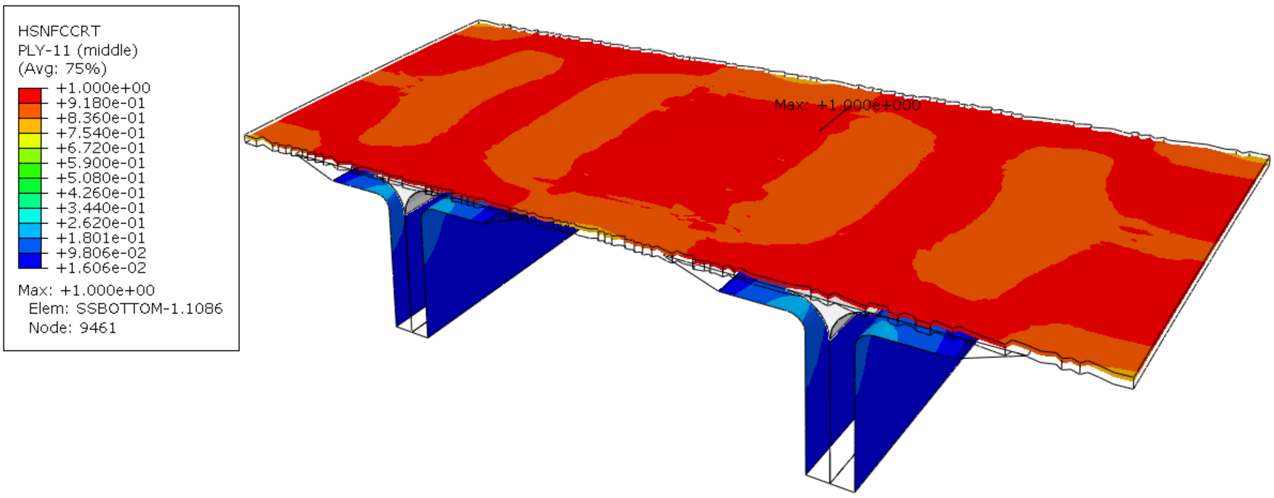


Figure 21 – Ply 11($+45^0$)

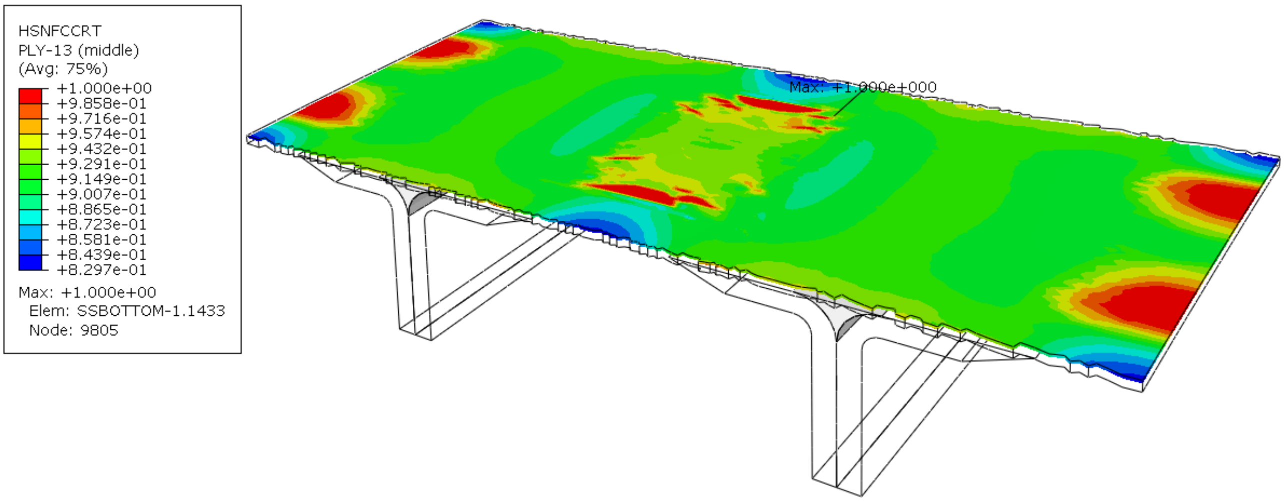


Figure 22 – Ply 13 (0^0)

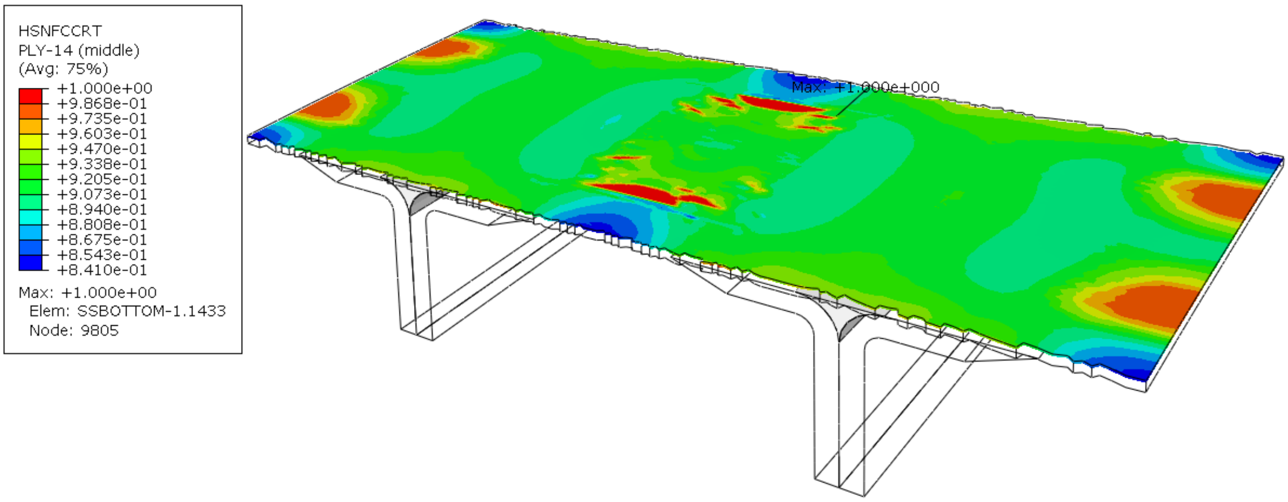


Figure 23 – Ply 14 (-45^0)

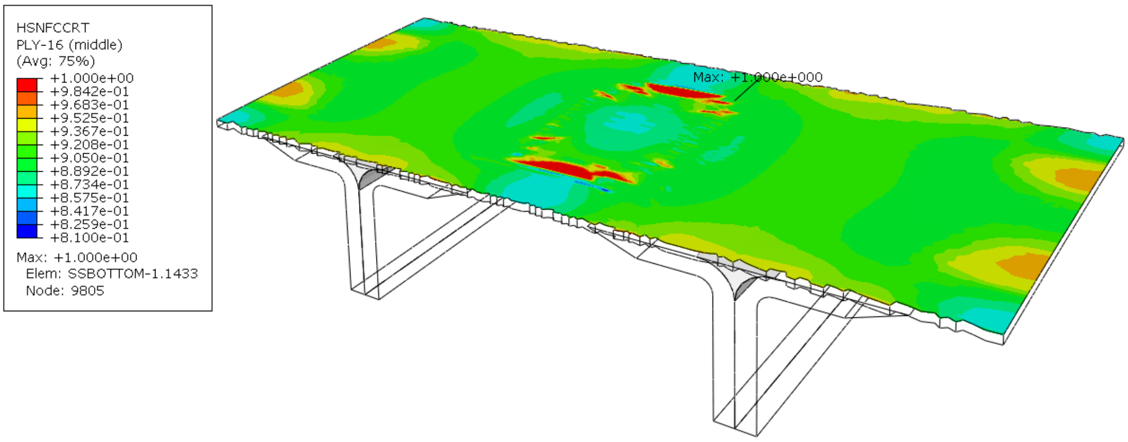


Figure 24 – Ply 16 (0^0)

The strain energy release at value U=1.91 and RF= 265 627, Figure 25

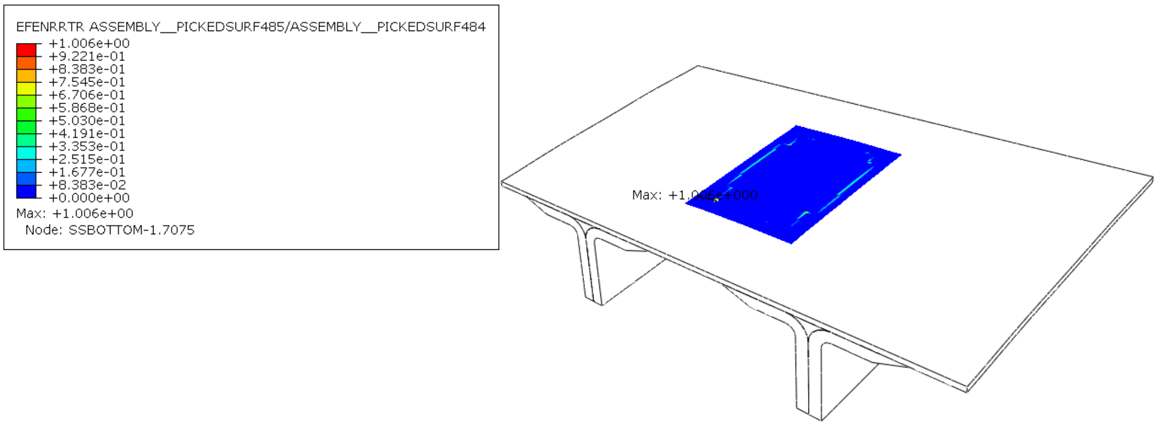
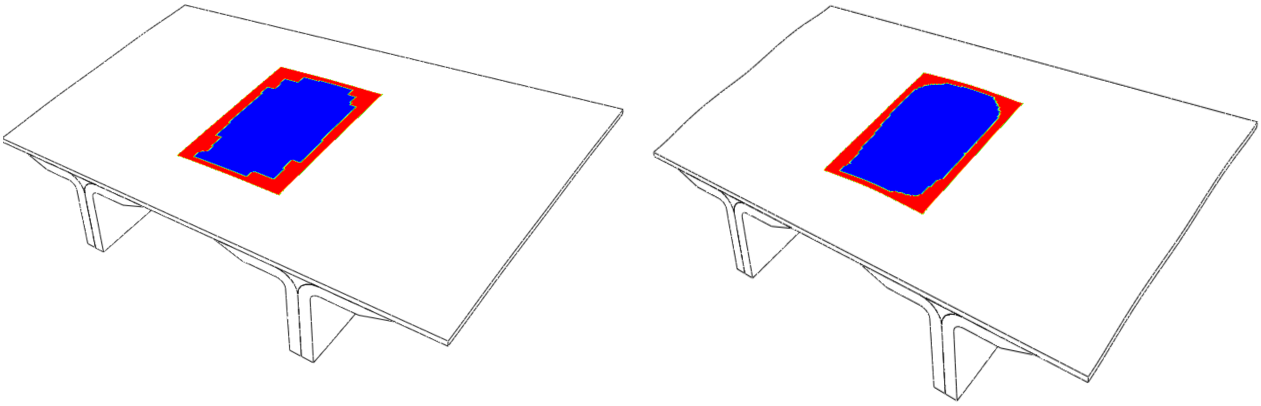


Figure 25 – Initiation of EFENRRTR, max

After energy starts to release the delamination goes on to accrue until the stress is removed, the delamination shape is shown below.



(a) *(b)*

Figure 26 – Delamination shape (a) – before, (b) - after

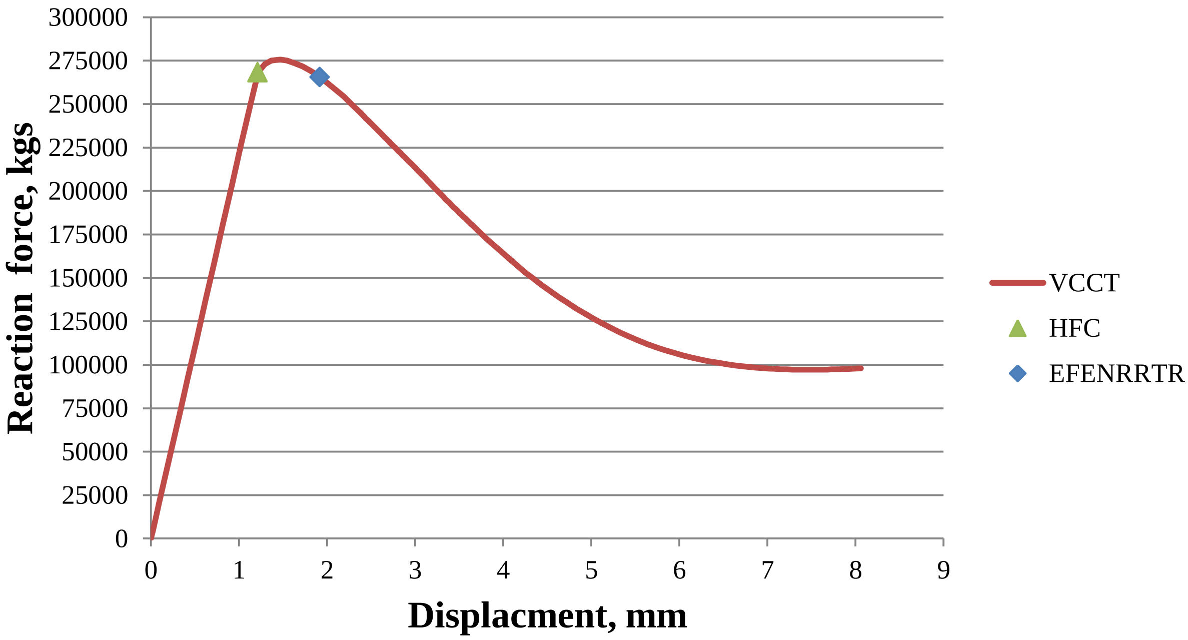


Figure 27 – Panel with defect, 90 Joules

The plot above shows: green point – Hashin criteria initiation, blue point – the strain energy release.

In the same way two different delaminations were tested after been subjected to impacts of 140 and 370 Joules, the analysis results are shown below.

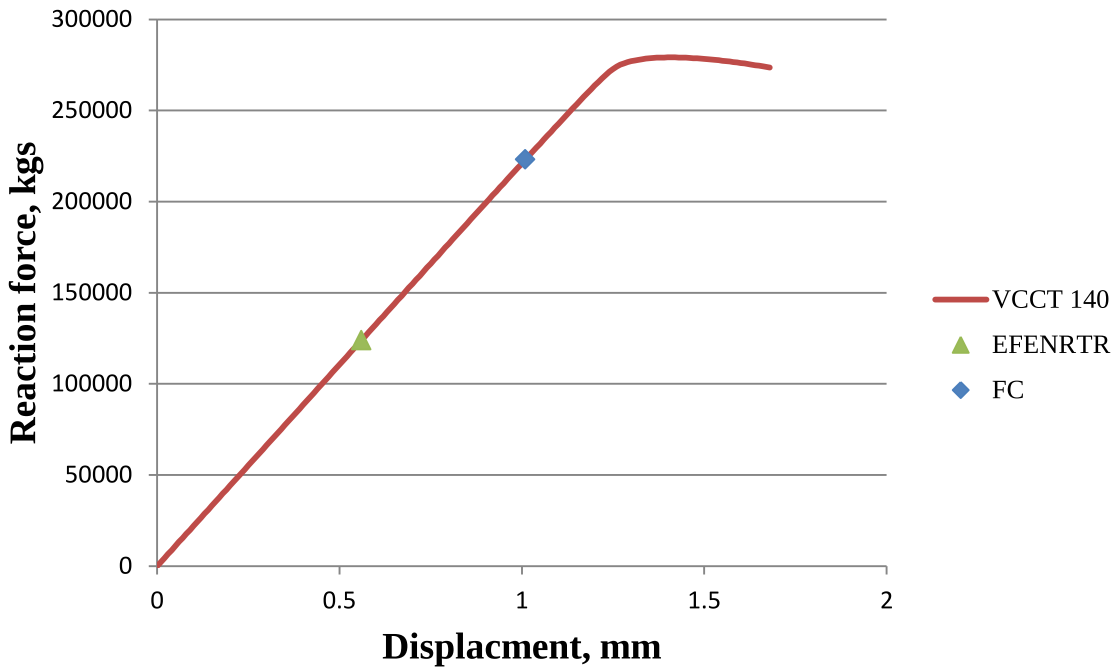


Figure 28 – Panel with defect 140 Joules

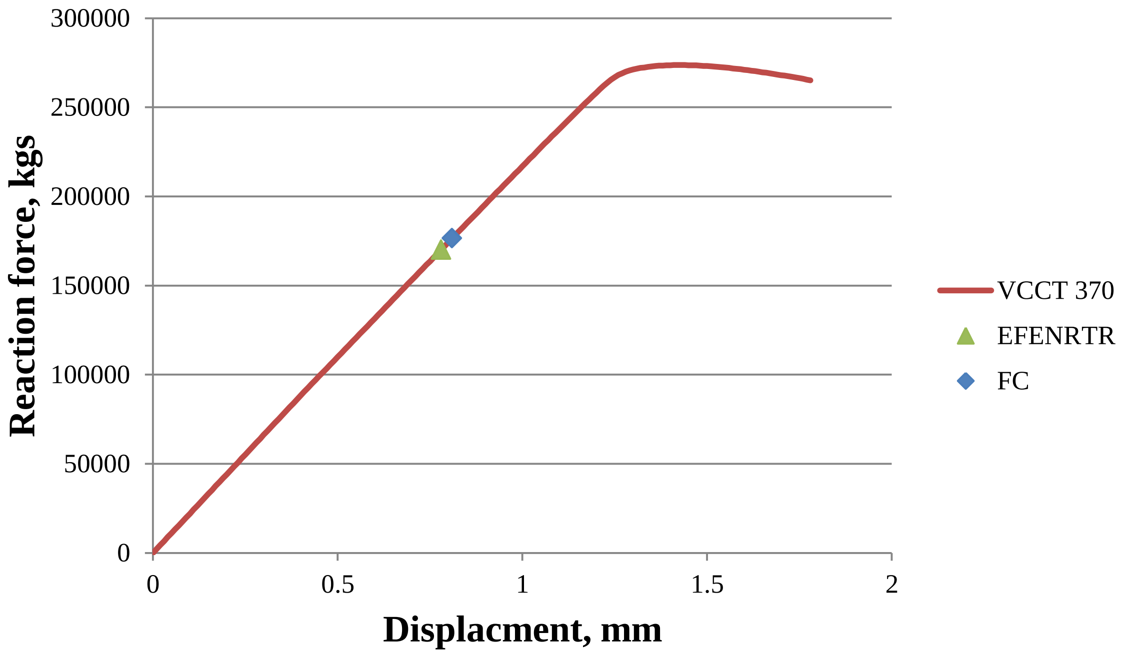


Figure 29 – Panel with defect 370 Joules

Finally, we've got the generalized diagram of results for panel with/without delaminations.

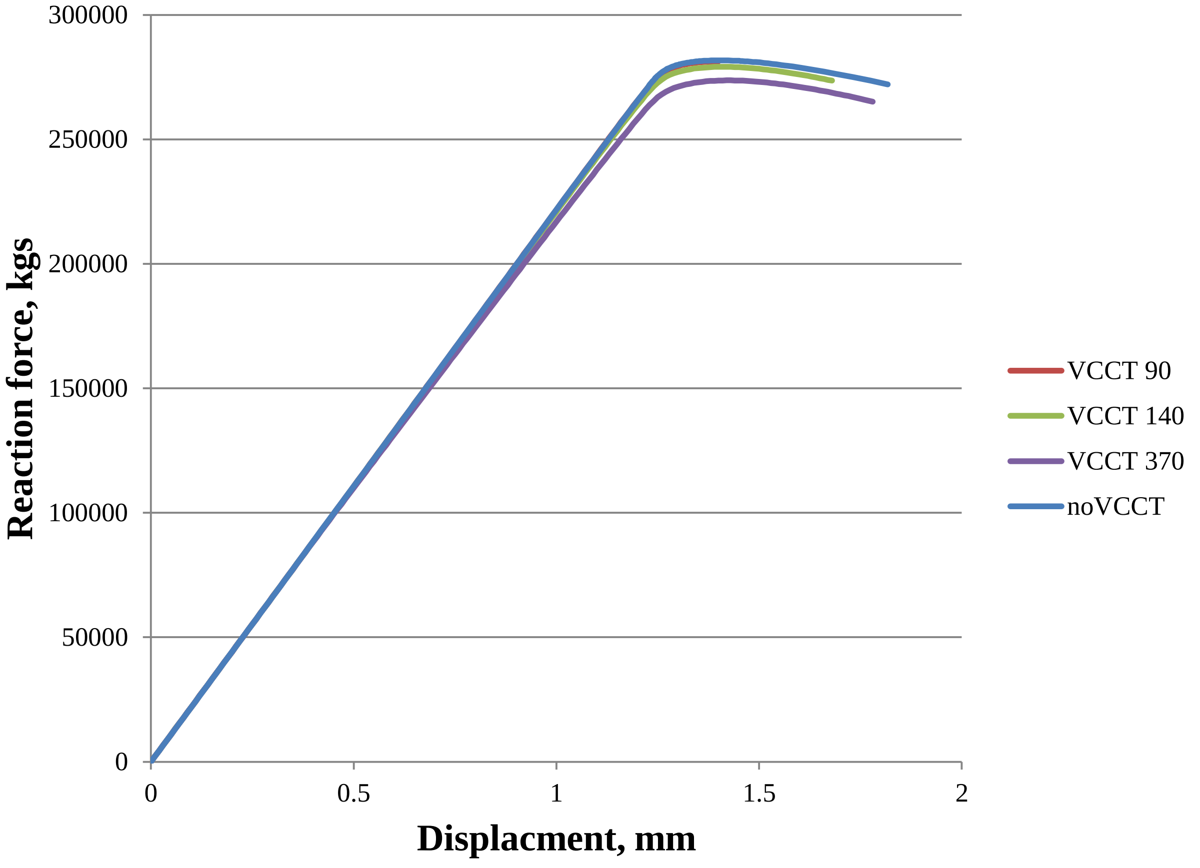


Figure 30 – Generalized diagram

Strength for panel without defect 281 738 kgs.

Strength for panel with defect 90 Joules 275 594 kgs.

Residual strength for panel with defect 90 Joules 97,82%

Strength for panel with defect 140 Joules 223 149 kgs.

Residual strength for panel with defect 140 Joules 79,2%

Strength for panel with defect 370 Joules 176 500 kgs.

Residual strength for panel with defect 370 Joules 62,64%

6. Conclusion

The paper is devoted to strength analysis of carbon fiber specimen consisting of skin supported by two stringers. The analysis was divided into two parts:

1. Strength determination of the panel without delamination;

2. Determination of residual strength of the specimens with damage (delaminated area after impact of 90, 140, 370 Joules energy).

The main result of this paper is a comparative chart curve of loading the specimen with and without delamination. The residual strength of the specimen: after strike 90 was 97.82%, after strike 140 was 79.2%, after strike 370 was 62,64%. It can be considered that the presence of delamination after impact with of 90 Joules energy does not affect greatly the panel residual strength.

7. References

1. Abaqus Users Manual, Version 6.12, Dassault Systémes Simulia Corp., Providence, RI.
2. Hashin Z. Failure Criteria for Unidirectional Fiber Composites. Journal of Applied Mechanics 1980;47:329-34.
3. Wu, E. M., and R. C. Reuter Jr., “Crack Extension in Fiberglass Reinforced Plastics,” T and M Report, University of Illinois, vol. 275, 1965.