Material Failure Approaches for Ultra High strength Steel

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Abstract:

The quest for predicting the material failure of ultra high strength steel introduces various approaches in simulations. BTR165 is ultra high strength steel used for safety beams in the vehicles. For the analyses of failure model, different profiles of door beams are selected. These door beams made of BTR165 are tested experimentally. Then the analyses for the similar profiles are done using LS-Dyna and compared with the test results. For BTR165, there is a very high local strain in the necking area compared to the gauge length strain. Based upon this, analyses are done to find a model that predicts the failure of the material during crash. LS-Dyna allows the analysis of the model based upon the plastic strain at failure and major in plane strain at failure strain *[1]*. To ensure the better material failure model for the ultra high strength steel, five different profiles of door beams are selected for the analyses. Analyses are done in LS-Dyna 970 based upon the local strain and global strain to find the best material failure model that can be compared to reality. Analyses are also done with different element sizes to find the influence of the element size. Depending upon this approach, a failure model for BTR165 is illustrated in this paper.

Keywords:

Global strain, Local strain, Failure prediction, UHSS, Necking

1 Introduction

Ultra high strength steel plays a major role in the automotive field. For the better performance and the safety purposes of the vehicle, the application of ultra high strength steel (UHSS) is increasing everyday. On the other hand, the product developers feel that the application of UHSS is confined to limited applications when referring the ultimate strain of the material from the tensile test. The better prediction of the crash performance of the components using CAE at an early stage not only reduces the time and money, but also improves the quality of the components. In the quest for finding the failure model for the materials, various approaches are made.

For the ultra high strength steels, there is a very high local strain in the necking area compared to the gauge length strain. BTR165 is ultra high strength steel used for the safety beams in the vehicles for its better performance. Tensile test is done for BTR165 to find the global strain in the gauge length and the local strain in the necking area. Based upon the global strain and the local strain, the analyses are done to find a model for BTR165 that predicts the performance of the components as in reality.

2 Properties of the steel

Tensile test is done to find the mechanical properties of BTR165. The local strain and the global strain of BTR165 are found out as described in the following procedures.

2.1 Test Set-up

Tensile test is done with a high-speed digital camera. During the test, the deformation is captured in digital frames and the force is measured using load cells. The deformation of the specimen from the acquisition of the digital frame and the force gives the desired characteristics of the material. The elongation is measured at a gauge length of 24*mm* and at the necking area of 4*mm* simultaneously. A quasi-static test is performed with a nominal speed of 2*mm/min*.

2.2 Test specimen

The test sample is a flat specimen, which is 6*mm* wide in the measurement zone and 10*mm* wide in the clamping zone. A gauge length of 24*mm* (L0) has been defined to measure the elongation for the global strain and a length of 4*mm* is taken for the local strain in the necking area.
In the measurement area (L0), a series of squares of 2*mm* is painted in black and white alternatively as shown in *Fig. 1*. So it is possible to follow the squares along the frames with the high-speed camera. By this way, the elongation of the specimen in the necking area is measured along the two successive squares.

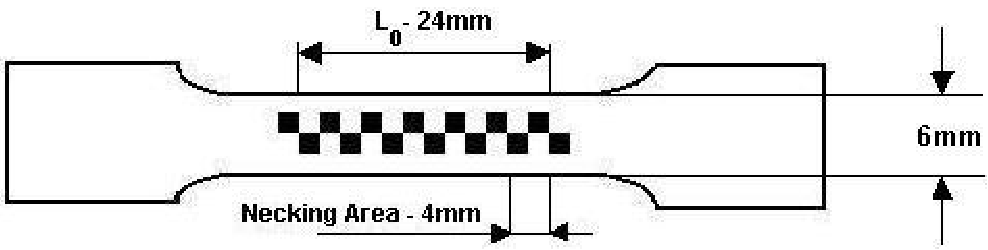

Fig. 1: Specimen for tensile test

2.3 Test results

BTR165 is tested as per the above description to find the global strain and the local strain with a nominal speed of 2*mm/min*. As mentioned above, the elongation is measured using the digital frames in the squares areas. The results shows that the test specimen has the similar characteristics in the gauge length, L0 and in the necking area up to certain time (80*sec*) and after 80*sec*, the difference between the two characteristics becomes more until the breakage of the specimen as shown in *Fig.2*. From the test results, it is found that BTR165 has a global strain of 9% and a local strain of 31%. The stress strain curve is depicted in *Fig.3*.

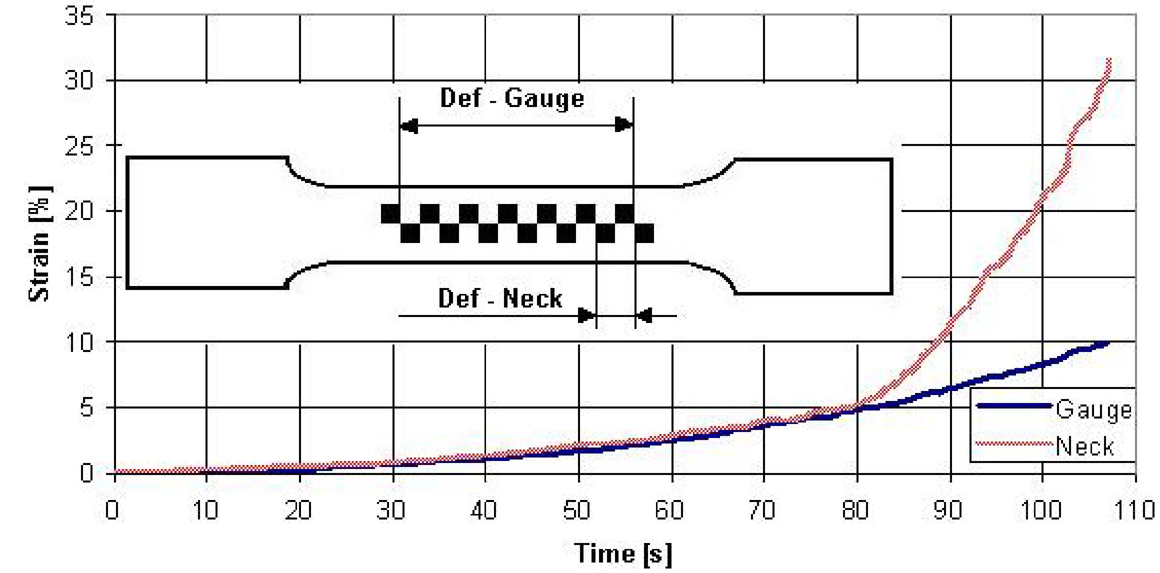

Fig. 2: Global and local strain of BTR165

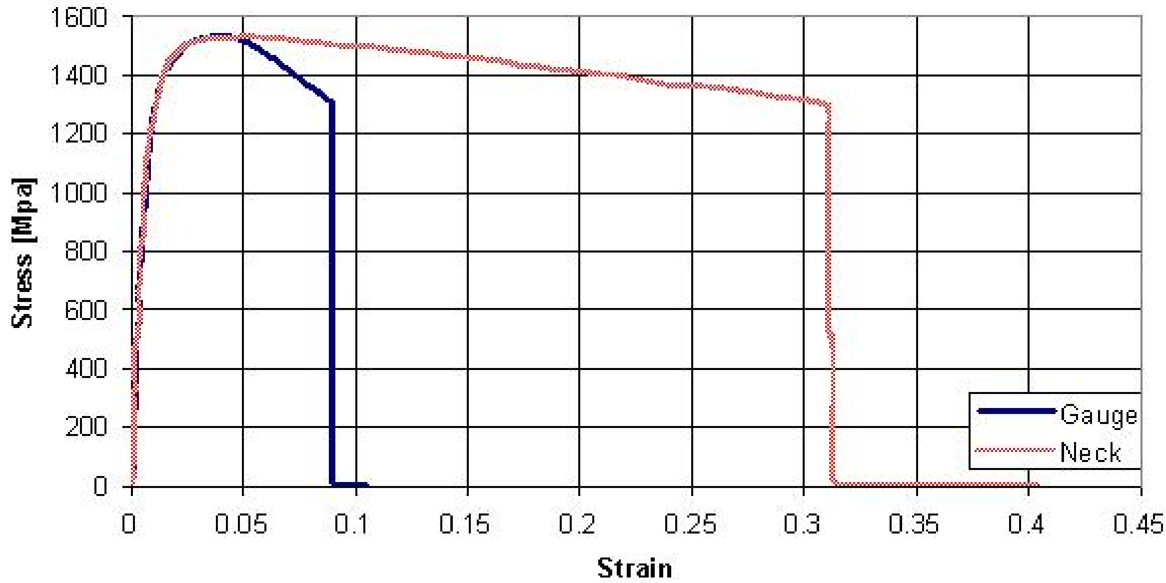

Fig. 3: Stress – Strain curve of BTR165

3 Failure Model

For the analysis of failure model for ultra high strength steel, BTR165, five different profiles of door beams are selected. These door beams made of BTR165 are first tested experimentally and then the similar profiles are analysed using FEM with LS-Dyna under the same test conditions. These profiles are analysed using different parameters in LS-Dyna to find the best model that can be compared with the test results.

3.1 Test set-up

The door beams are tested experimentally according to 3 point bending test. The experimental set up is as shown in *Fig.4*. A small barrier of radius 15mm is used to apply force on the door beams. The test is done at a speed of 4*mm/sec.* The maximum barrier intrusion is 350*mm.*

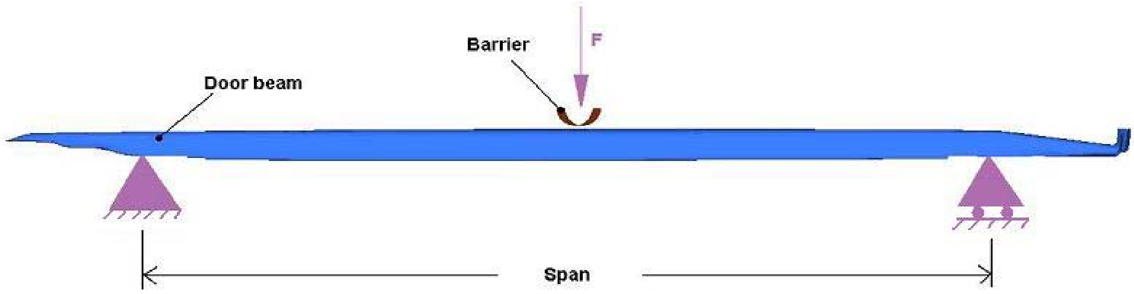

Fig 4: Experimental set-up of 3 point bending test

3.2 FE Analysis

The door beams are analysed in FEM using LS-Dyna 970 according to test conditions. The profiles are analysed based upon 3 point bending test using a rigid barrier with a radius of 15mm. The boundary conditions are taken according to the experimental set up as shown in *Fig.5*. Shell elements are used for the analysis. The thicknesses of the profiles are taken as shown in *Table.1* according to the component thickness.

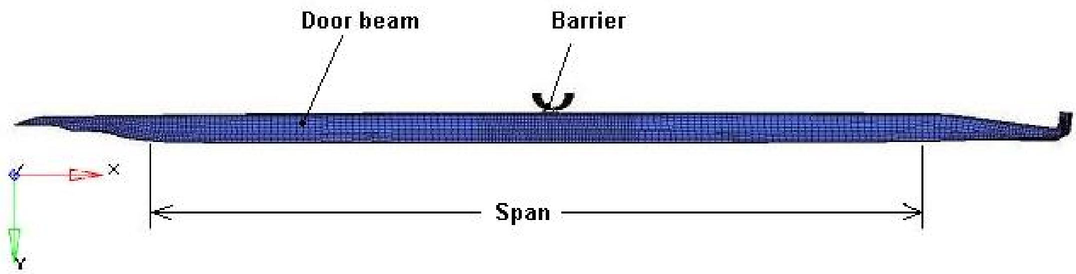

Fig 5: FE Analysis according to 3 point bending test

	3.2.1 Thickness [mm]	
	Component	CAE
Door beam – 1	*2.3 – 2.4*	*2.35*
Door beam - 2	*2.1 – 2.3*	*2.20*
Door beam - 3	*1.6 – 1.8*	*1.70*
Door beam - 4	*1.7 – 1.8*	*1.75*
Door beam - 5	*2.4 – 2.5*	*2.45*

Table 1: Thickness of the profiles taken for CAE based upon component thickness

The true stress-strain curve BTR165 used for the analysis is shown in the following *Fig.6*

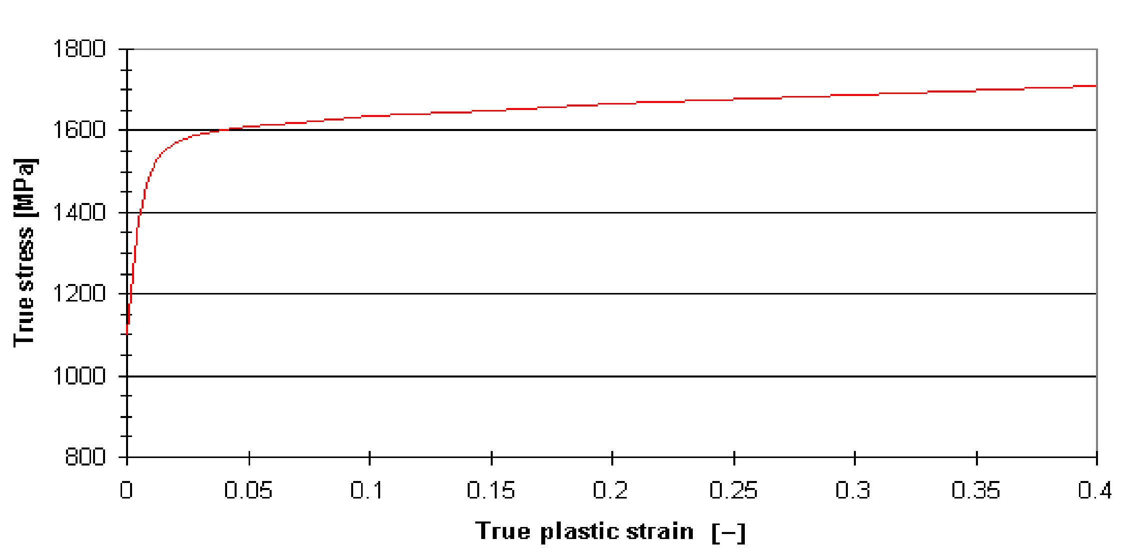

Fig 6: True Stress – True strain curve of BTR165

The door beams are analysed based upon global strain (9%) and local strain (31%) of BTR165. These profiles are analysed according to two Major criterions:
Model with plastic strain at failure
Model with major in plane strain at failure

For the shell elements in LS-Dyna 970, the material cards, *MAT_PIECEWISE_LINEAR_PLASTICITY (MAT24) is a material model with plastic strain at failure and *MAT_MODIFIED_PIECEWISE_LINEAR _PLASTICITY (MAT123) is a material model with major in plane strain at failure *[1]*. During the analysis, when all the thorough thickness integration points in a element reach the prescribed failure criteria, then the element is deleted. The analyses are done with the shell elements of 4mm element size.

From the analysis, it is found that the when the global strain is taken as a failure criteria, the models break at an early stage compared with the test results as shown in *Fig.7*. But if the local strain is taken as the failure criteria, then the model does not break so early. From the *Fig.7*, it can be clearly seen that the model with major in plane strain at failure based upon the local strain (31%) is better and can be compared with the test result. The following *Fig.7* shows the results of door beam.1.

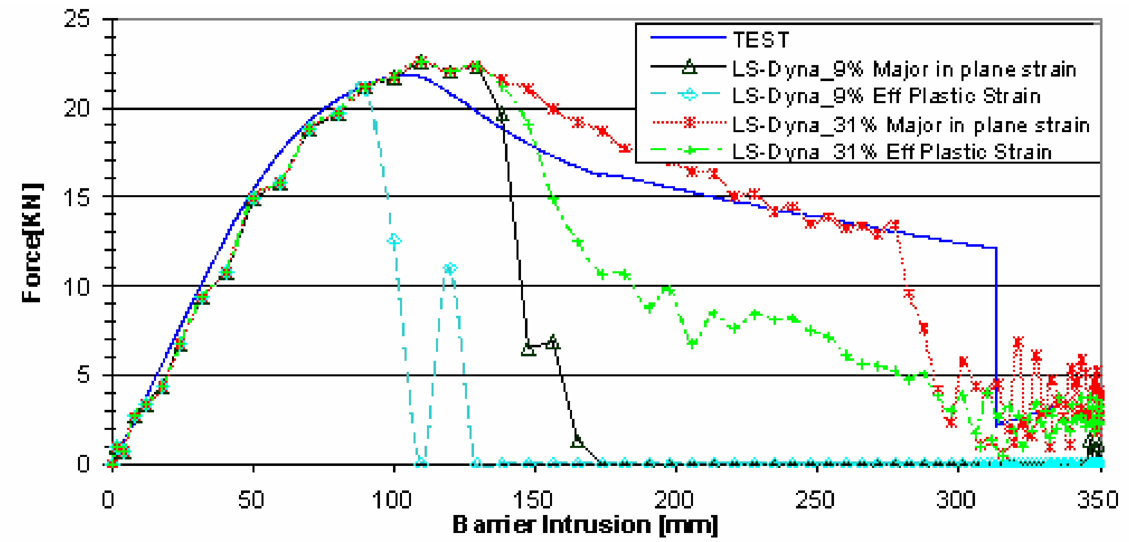

Fig 7: Comparison of FE analyses based upon global strain and local strain with test results

As the model with major in plane strain at failure based upon the local strain shows the better results, efforts are made to find the influence of the element size of the shell elements. The models with element sizes of 2mm, 4mm and 8mm are analysed. It is found that the model with the element size of 2mm fail early when compared with the test result and the model with the element size of 8mm fail later when compared with the test result as shown in *Fig.8*.

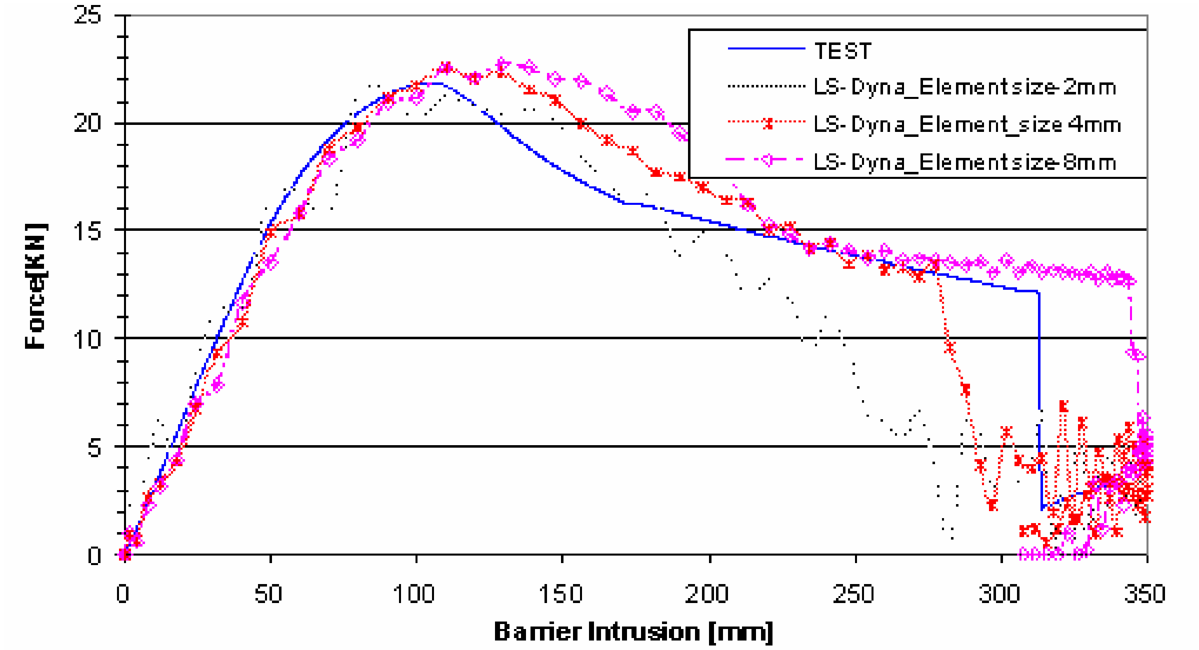

Fig 8: Comparison of FE Analyses with different element sizes with test results

The following *Fig.9* depicts the comparison of the component and the profiles of doorbeam-1 with different element sizes. It is evident that the model with the element size of 4mm is better compared with the other two models.

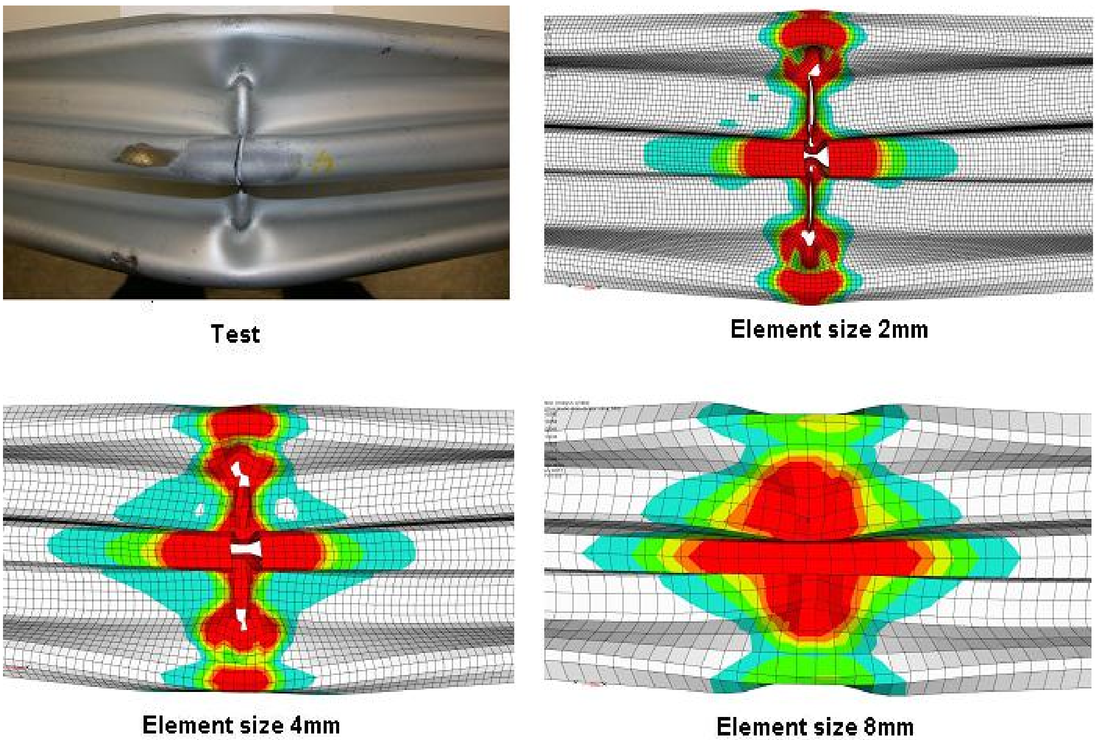

Fig 9: Comparison of the component with the FE models when the barrier intrusion is 315mm

The following *Fig.10* shows the summary of the results of five different profiles of door beams taken for analyses. FEM analysis of the models based upon major in plane strain at failure and model based upon plastic strain at failure in LS-Dyna are compared wit the test results. It is evident that the model with local strain based upon major in plane strain at failure shows good failure prediction as in reality.

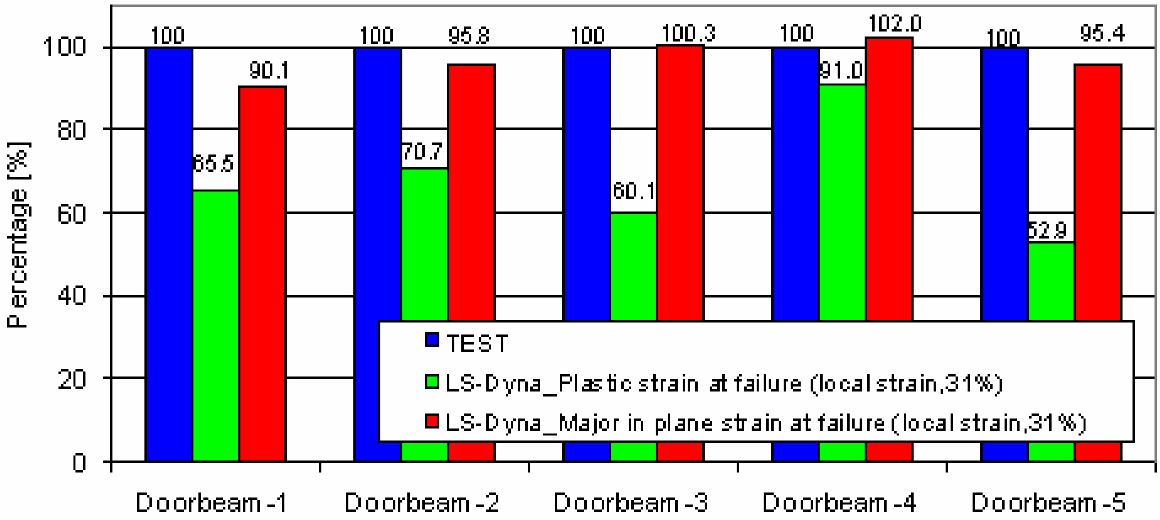

Fig 10: Summary of the 5 different profiles of door beams with the test results

4 Conclusion

The demand for better performance of the components in the vehicles prompts wide usage of ultra high strength steel in the automotive industry. The better prediction of the breakage of the components in an early stage in CAE saves time and money. Various approaches for the prediction of failure model of the ultra high strength steel, BTR165 are made with different profiles of door beams using LS-Dyna 970. BTR165 has a very high local strain compared to the global strain. When the analysis is done for the UHSS, BTR165 with the global strain as the failure criteria, the model fail very early when compared with the test results. But if the local strain is taken into consideration as the failure criteria, the model does not fail early. Furthermore, based upon the local strain, it is found that the model with major in plane at failure shows better results than the model with plastic strain at failure when compared to the test results. Thus for the ultra high strength steel, BTR165, the model based upon the local strain with major in plane strain at failure gives the better prediction of failure and can be compared in reality.

5 References

[1] LS-Dyna Keyword user's manual, Version 970, Livermore Software Technology Corporation, 2003

[2] H. Gese, H. Werner, H. Hooputra, H. Dell, A. Heath.; A Comprehensive failure model for metallic structures in Sheet metal forming and Crash simulation, Europam2004 Conference, Paris, 2004