# The Effect of Rubber in Strength Analysis for Strut Insulator Assembly

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***Abstract**: The strut insulator assembly in the suspension system which supports shock absorber, spring and bump stopper takes large upward load when vehicle crosses pot hole or speed bump with high speed. As the permanent deformation of insulator bracket could cause noise problem, the development of insulator bracket strength is required. Though the main bumper stopper load applied to steel bracket directly in the inner core type insulator, there is rubber between steel bracket and bumper stopper in the cup molded type insulator. Because there could be some convergence problem caused by large deformation of rubber, the modeling and strength analysis procedure for the cup molded type insulator is set up in this study. A series of step-by-step trials would give an insight in setting up an analysis procedure of similar problem. The Yeoh hyper-elastic model for rubber material property is used when the large load is applied to rubber and the strain is high. However rubber increases the strength of permanent deformation, the change of rubber stiffness does not have a great influence on the strength result. Although the total displacement and initial stiffness of system is quite different, the comparison between test and analysis with different bush stiffness gives same strength level.*

***Keywords**: Assembly Deformation, Hyperelasticity, Rubber, Strut insulator, Suspension*

## 1. Introduction

The strut assembly is the main part which sustains body of vehicle against various types of load. It is composed of spring, shock absorber and bumper stopper. Also there is an insulator assembly at the top of this system to link suspension and body of vehicle. It is composed of core, bracket and rubber (Fig.1). Rubber which is attached to both sides of core and bracket isolates small vibration from road. Large upward force caused by pot-hole or speed bump on the road is transferred to insulator assembly through bumper stopper. If the strength of insulator assembly is not enough, the permanent deformation or break of bracket could happen. Because the permanent deformation of bracket can make some squeak noise during running, the strength development of bracket is required. Inner core type strut insulator assembly in which core and rubber are enclosed by bracket is widely used so far. However it is simple and robust, there could be some noise at the contact region between strut rod and bumper stopper. This noise caused from the independent motion of strut rod and bumper stopper. In this point of view, cup molded type strut insulator in which strut rod and bumper stopper moves as one part is better choice. As the emotional quality including noise is going to be critical sales point, the cup molded type insulator is adopted more than ever. In the strength analysis of insulator assembly, these two types of insulator systems have quite different load path. The upward load from the bumper stopper in the inner core type strut insulator is applied only to the bracket and rubber could be ignored during strength analysis. But there is rubber in the load path of the cup molded type strut insulator and the large load transfer through rubber gives some troubles in the implicit analysis. Some results for case studies during establishment of strength analysis process for the cup molded type will be shared in this work.

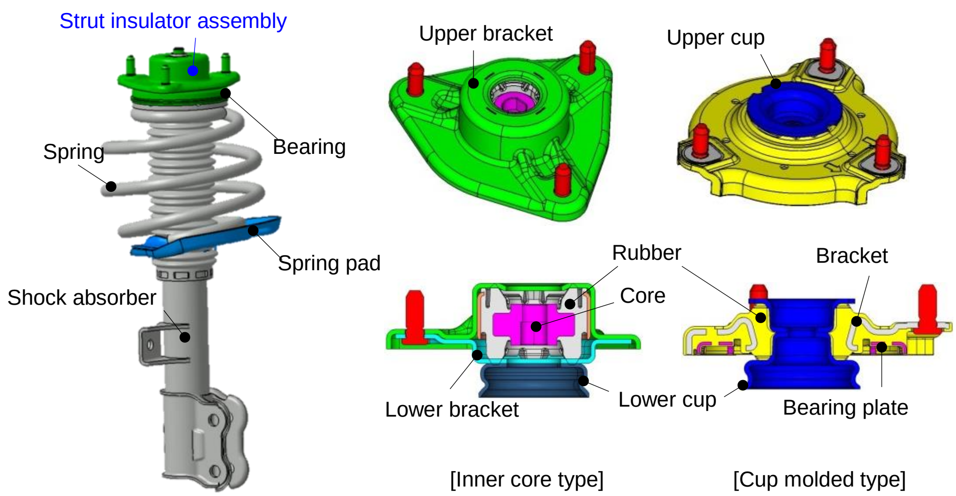



**Figure 1. Two types of strut insulator assembly and their structure**

## 2. Strength analysis for inner core type insulator

A plunger gives load to the bracket which is put on the jig in the strength test of the insulator assembly. The bottom area of the plunger is same with that of bumper stopper. The change of inclination in the force-displacement curve means the start of permanent deformation for the inner core type insulator assembly and that force level is checked as the strength. The strength analysis for this type is simple and the analysis result shows quite good correlation between analysis and test (Fig.2).

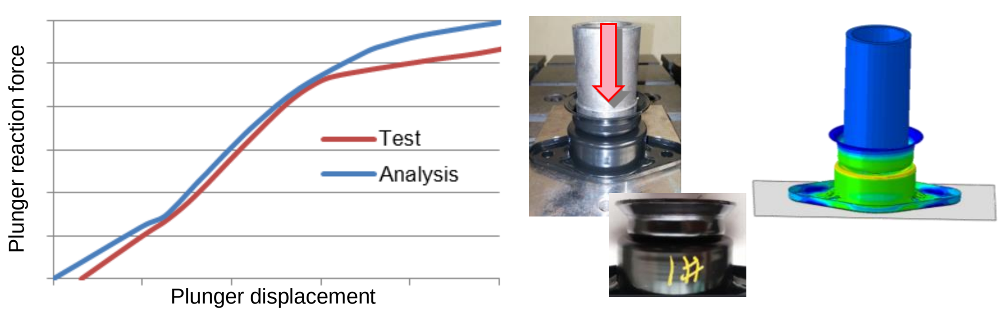



**Figure 2. Strength analysis and test result for inner core type**

## 3. Strength analysis for cup molded type insulator

### 3.1 Composition of analysis model

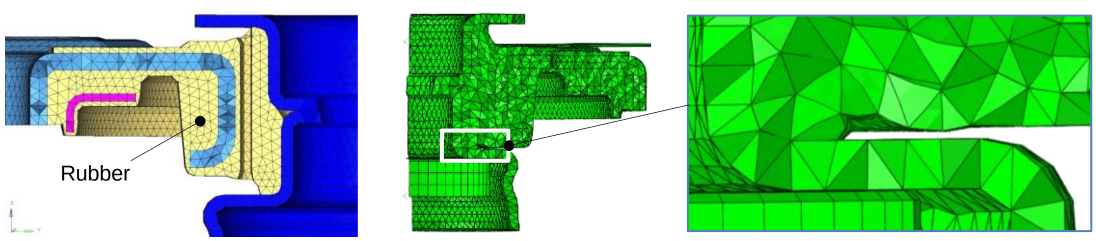
Rubber is molded with lower cup and bracket at the same time and then upper cup is inserted to the top of the assembly. A bearing plate which sustains bearing for spring is also molded at the same time. Sometimes stopper plate could be added at the lower cup to restrict upward displacement of strut rod. The materials for cup, bracket and bearing plate are some sorts of steels as shown in the Table 1. The material property for rubber is selected from our suspension rubber material database which is made up with SIMULIA and AXEL PRODUCT according to the Shore A hardness scale. However the selected rubber is not exactly same with that of insulator, the effect of rubber property to the permanent deformation of metal parts might be in relative small. To see the effect of rubber material, another rubber with different hardness is tested in this analysis. The Yeoh hyper-elastic material model is used as rubber material property because stability at large strain is required. The loading and boundary condition for the strength analysis are same with those for the inner core type test.

**Table 1. Material list used in this analysis.**

| Part | Material name | | Rubber | Shore A hardness scale |
|---|---|---|---|---|
| Cup | SAPH440 | | Original | Hs55 |
| Bracket | SAPH440 | | Compared | Hs70 |
| Bearing plate | SPCC | | | |

### 3.2 Rubber model with fine C3D10H element

The second order tetrahedral element is used in finite element modeling, C3D10 for steel plates and C3D10H for rubber with less than 2mm element length (Fig.3). Nodes on bolted to jig are fixed and contact pairs are assigned between jig and bracket interfaces. Rigid elements are used for jig and plunger. Jig is fixed at the reference node and the plunger is able to move freely only in the stroke direction. As plunger presses rubber, the distortion of element happens easily. At last the analysis diverges with only little stroke. Convergence might be impossible with C3D10H in this case.




Section view of FE model

Distortion of rubber element during analysis

**Figure 3. Strength analysis with fine C3D10H element in rubber**

## 3.3 Rubber model with fine C3D4H element

To avoid distortion problem of rubber element, first order tetrahedral element, C3D4H, is used for rubber. The stroke of plunger is larger than before and the distortion of element is removed. However the contact between rubber and lower cup happens normally, some rubber elements curl up in a ball (Fig.4). Nodal residual forces at those nodes are too large to converge. This means that curling up of rubber element is the main problem to resolve.

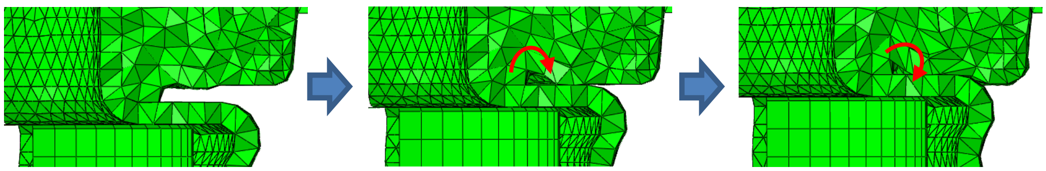


**Figure 4. Strength analysis with fine C3D4H element in rubber**

## 3.4 Rubber model with coarse C3D4H element

To remove curling up problem of rubber, rubber elements are re-meshed using larger element length (Fig.5). The stroke of plunger is long enough to see the permanent deformation of steel plates in this case. The slope change happens twice in the force-displacement curve of plunger. First change happens when contact between lower cup and rubber starts and the second change happens when permanent deformation of steel bracket starts. So the force at the start point of second slope change is the strength value for this bracket. However it is easy to generate tetrahedral element using automatic mesh generator in pre-processor, it is difficult to control mesh shape of rubber inside. It can give rise to the curling up of elements from time to time. Besides, first order tetrahedral element is well known for stiff behavior. For these reasons, another stable method of modeling is required.

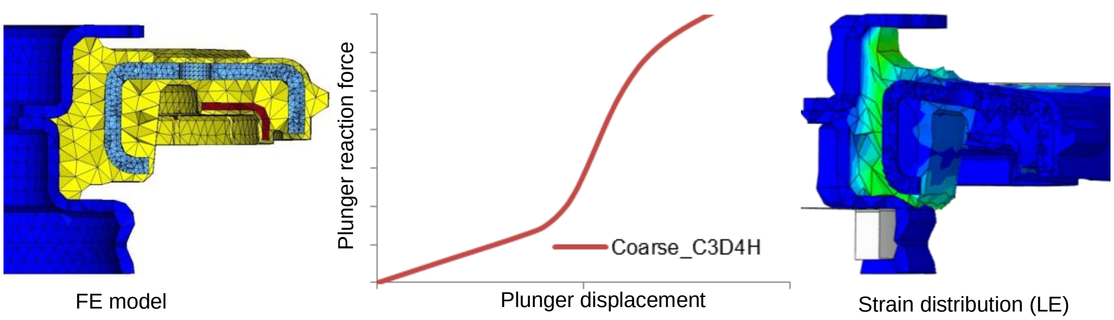



**Figure 5. Strength analysis with coarse C3D4H element in rubber**

### 3.5 Rubber model with fine C3D8H element

It is not easy to make hexagonal element in rubber part because the outside region of rubber part is not the cylindrical shape. To save modeling time, reducing modeling region which does not affect largely to the strength analysis in rubber part is required. Strain distribution result in the previous analysis (Fig.5) shows no contribution of rubber elements outside from bearing plate to the result. However the ignoring outside part of rubber in meshing makes modeling much easier, the curling up problem of rubber elements (Fig.6) happens again. The comparison of force-displacement of plunger shows that the stiffness of first order tetrahedral element is too large, also. The solution for removing curling up problem is now adopted.

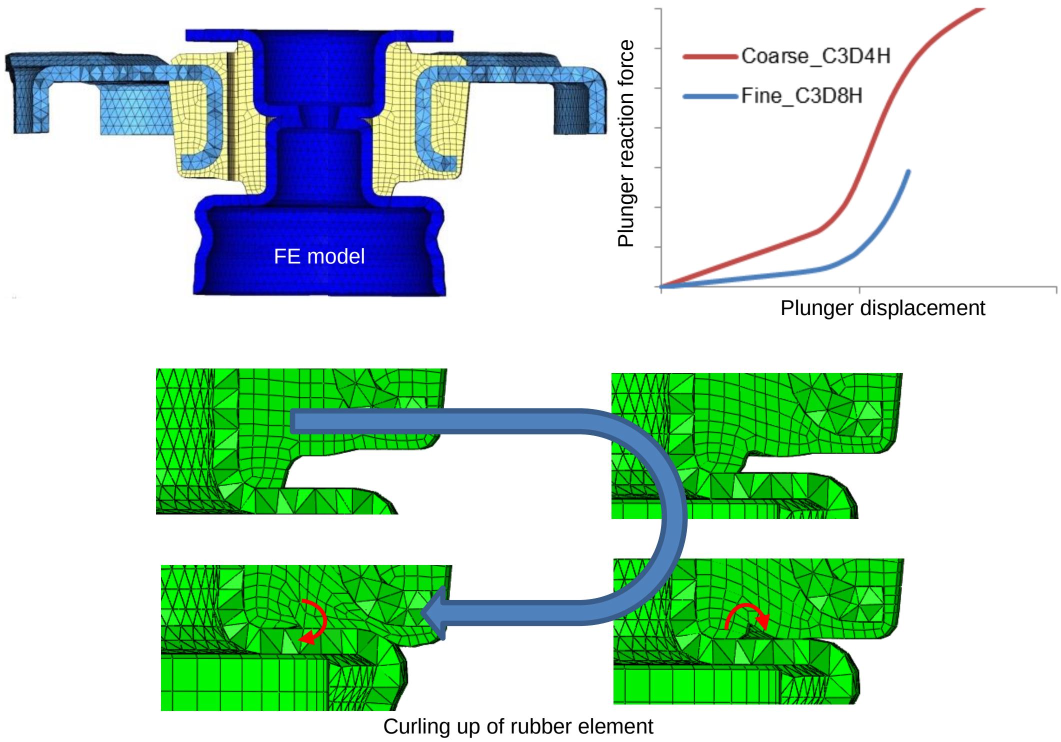



**Figure 6. Strength analysis with fine C3D8H element in rubber**

### 3.6 Rubber model with coarse C3D8H element

It is simple to compose coarse rubber model from finer one and the strength analysis ended up successfully. The force-displacement curve (Fig.7) shows that the stiffness difference between fine and coarse element of rubber is ignorable. However the second change of the slope from the coarse first order tetrahedral element seems to be same with this result, it is necessary to check up the effect of rubber stiffness to the start of permanent deformation of steel bracket.

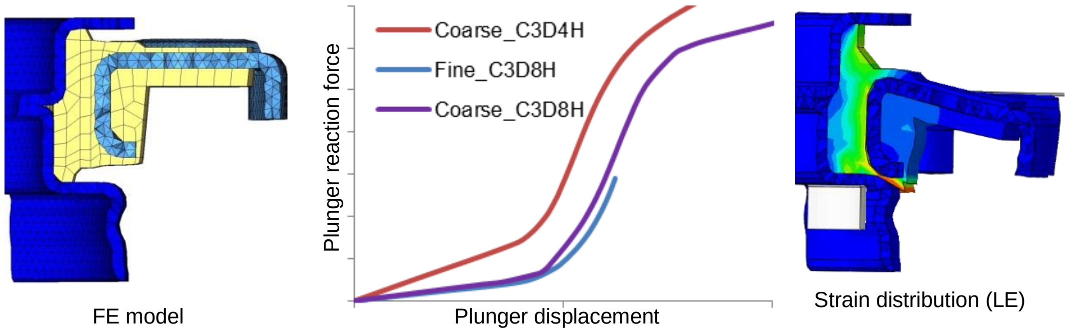



**Figure 7. Strength analysis with coarse C3D8H element in rubber**

### 3.7 Rubber hardness effect to the permanent deformation of bracket

Two different rubber materials in Shore hardness scale, Hs55 and Hs70, are used in the same FE model (Fig.8). The harder rubber increases the initial slope of force-displacement curve of plunger as expected. But, the second and third slopes are almost same with the softer one. Moreover, the reaction force when the second change of slope starts is exactly same. If the element type is same, the strength of bracket does not differ according to the rubber stiffness.

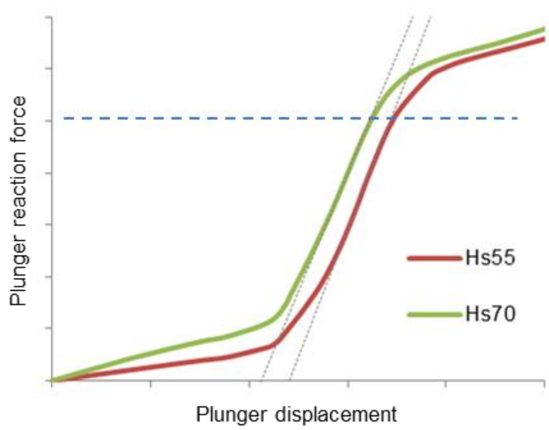



**Figure 8. Rubber hardness influence to the bracket strength**

### 3.8 Comparison with the test

The test and analysis results of a cup molded type strut insulator for mid-size sedan are compared (Fig.9). However the rubber stiffness in analysis differs from test specimen, the strengths for permanent deformation are almost same. As the convergence with softer rubber material tends to be bad, it is helpful to use harder rubber for improving convergence. So, the standard material property for insulator rubber is selected as somewhat harder one according to this result.

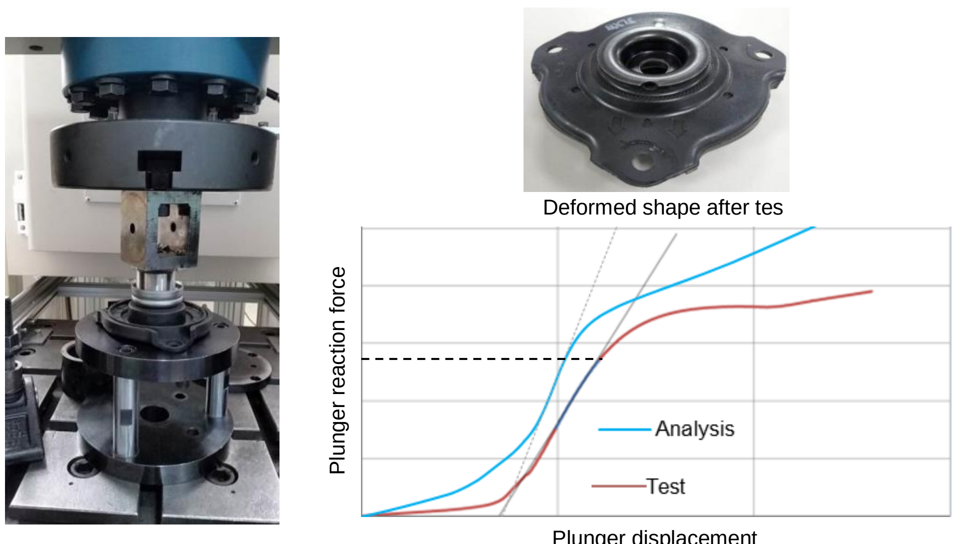



**Figure 9. Analysis and test result comparison**

## 4. Conclusion

The modeling and strength analysis procedure for the cup molded type insulator are set up in this study. The Yeoh hyper-elastic material model gives successful convergence during large load application. However the difference of rubber hardness makes the difference of initial slope in force-displacement diagram, it does not have a great influence on the permanent deformation of steel bracket. It is no need to have all rubber tested to get precise material properties when the analysis is focused on the strength of steel parts. But precise rubber material properties should be required when the global displacement and the strain of rubber are important such as controlling gap problem or durability of rubber.

## 5. References


1. Abaqus Users Manual, Version 6.12, Dassault Systémes Simulia Corp., Porvidence, RI.
2. Robert H. Finney,"Engineering with Rubber", 1992.