

Effect of Stress Softening in Bumper Foams on the Low Speed Impact Performance of Vehicles

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ABSTRACT

The experimental findings have revealed that there is a significant stress softening phenomenon for the polymer foams used in vehicle bumpers after they are loaded repeatedly from the raw undeformed state. With a series of loading-unloading test data under different maximum strains, dependence of the stress softening on the deformation history is analyzed. The corresponding material models in ABAQUS are chosen to characterize such special features of the polymer foams in FEA. The low speed impact models of a subsystem consisting of a bumper assembly and front-rails are established, and a process for transferring the deformation history of the bumper foams between the consecutive impact-loading cases is set up in the environment of ABAQUS. Based on the FE simulations, it can be seen that the stress softening of the polymer foams compromises the low speed impact performance of bumpers in subsequent impacts. Therefore the stress softening effect of polymer foams should be taken into account during safety designs of vehicle bumpers.

INTRODUCTION

The foam cushion behind the vehicle bumper fascia is a typical example of polymer foam application in vehicle bodies. In general, it serves as an energy-absorption mechanism during the low speed vehicle collisions or the pedestrian leg impacts. After a low speed collision, if the bumper deformation almost fully recovers within a certain time period, the foam cushion is often reused without any treatment. This is in line with some regulation requirements, for instance, an item in the conditions governing repair, replacement and measurement in Annex 3 of ECER42 (low-speed-impact test procedure) brings forward the recovery time requirement for the "self-restoring" materials [1]. However, the definition of "self-restoring" is somewhat ambiguous, i.e., it is not clear whether the deformation recovery or the load-carrying capability recovery is of concern for the materials. The deformation recovery seems to be always preferred. In reality, this may lead

to misuse of the bumper foam cushions. Sometimes, when checking the real-world accident with photograph approaches, the actual damage on the steel bumper beam may easily be ignored if the photograph indicates no visible damage on the bumper foams [2].

Researches have revealed that there is a stress softening effect, referred to as Mullins Effect [3], for elastomers. Similar phenomenon can be observed for elastomeric foams, even though few experimental results have been reported [4-6]. For elastomeric foam samples undergoing repeated loads, their shapes could almost self-recover no matter after the first compression or after the subsequent compressions. However, to achieve the same level of deformation, only a much lower force is required in the subsequent compressions than that in the first compression. That means the capability of energy absorption is greatly reduced after the elastomeric foam experiences the first loading-unloading cycle.

A previous investigation by this team [7] has checked out the effect of such stress softening of foam materials on the low speed impact performance of the bumper subsystems. Two consecutive impacts are simulated respectively, in which the same model of bumper subsystem is used except the material property of the foam cushion. For the first impact, the original stress-strain curve of the foam material is used in the whole foam cushion; for the second impact, the stress-strain curve after softening is used. However, such a treatment somewhat deviates from the reality. The fact is that, after the first impact, different regions in the foam cushion may have different deformation histories.

As an improvement, in this paper, how the deformation history affects the stress softening of the foam is first identified via material experiments, and then a simulation process to transfer the deformation history of the foam cushion is established. Based on these preparations, simulations of consecutive impacts with detailed FE models of a bumper subsystem are carried

out, and the stress softening effect of the foam cushion is evaluated in detail.

EXPERIMENTAL STUDY ON DEFORMATION HISTORY DEPENDENCE OF STRESS SOFTENING

Cube-shaped specimens with the dimensions of $50 \times 50 \times 50 \text{ mm}^3$ are cut from a real bumper foam cushion, and their uniaxial loading-unloading compression tests are performed on a servo-controlled electro-hydraulic testing machine, under three different maximum strains, 25%, 60% and 90%. Force-displacement curves of one specimen are shown in Figure 1, from which it can be seen that significant softening exists between the first loading and the subsequent loading, and the softening manner depends greatly on the deformation history. The maximum deformation in the loading history, $\Delta U_{\max}$, functions like a threshold. When the current deformation is below $\Delta U_{\max}$, the material behavior is accordant with the stable curve after softening at the level of $\Delta U_{\max}$. When the current deformation exceeds $\Delta U_{\max}$, the material behavior would trace the primary curve before softening. At a new level of $\Delta U_{\max}$, the stress softening would also significantly take place for the subsequent compressions.

NUMERICAL TECHNIQUES TO CHARACTERIZE STRESS SOFTENING AND TRANSFER DEFORMATION HISTORY

ABAQUS software (V6.6) is used in the simulations in this paper. Similar to characterization of the Mullins effect of elastomers, the stress softening phenomenon of foams can be modeled with the combination of two material models in ABAQUS, i.e., HYPERFOAM and MULLINS EFFECT [8]. The HYPERFOAM model is based on the strain energy potential for compressible elastomers proposed by Storåkers (1986) [9], and the MULLINS EFFECT model is based on the phenomenological characterization of the stress-softening for elastomers proposed by Ogden and Roxburgh (1999) [3], which has been modified for compressible materials. The elastomeric foam behavior before softening is defined by the HYPERFOAM model with the primary stress-strain curve in the entire deformation range to be investigated, as shown with the curve T0 in Figure 2. The softening manner can be defined by directly specifying the damage parameters of MULLINS EFFECT or by inputting test data to calibrate the relevant parameters. The latter approach is adopted in this paper and the curves T1 ~ T3 shown in Figure 2 are inputted. It should be noted here that these material models have not yet included the characterizations of the temporary hysteresis phenomenon and the small residual deformation during the loading-unloading cycles which could be found from the test results, as shown in Figure 1.

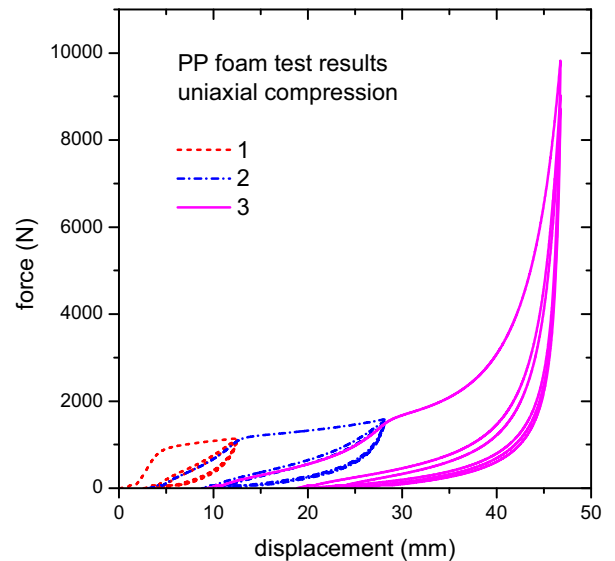


Figure 1. Loading-unloading cycles of an elastomeric foam sample at different deformation levels: 1 – 25% compression; 2 – 60% compression; 3 – 90% compression.

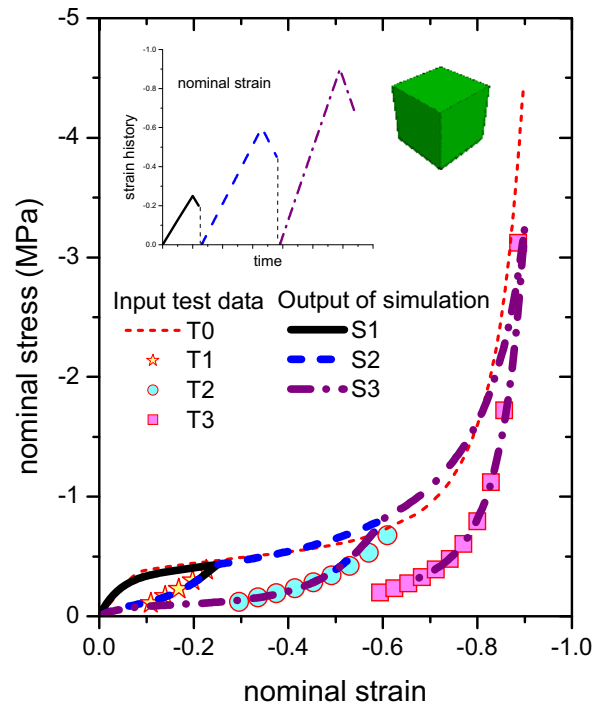


Figure 2. Stress-strain curves of the input and output of a single-element simulation: T0 – primary loading curve before softening; T1 ~ T3 – stable loading curves; S1 ~ S3 – curves of simulated loading-unloading cycles; T1 and S1 – 25% compression; T2 and S2 – 60% compression; T3 and S3 – 90% compression.