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Influence of stress softening on energy-absorption capability of polymeric foams

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ABSTRACT

The energy-absorption capability of the polymeric foam used in vehicle bumpers is investigated through cyclic loading tests in different loading types, including uniaxial compression, biaxial compression and three-point bending. The test results indicate, due to significant stress softening, the energy-absorption capability of the bumper foam is greatly reduced after it is repeatedly loaded from the raw state. It is also revealed that both the softening effect and the reduction of energy-absorption are dependent on the deformation history. To account for the softening effect as well as its dependence on deformation history in simulation of the bumper foam, appropriate material models are identified and a modeling approach is developed. Using consecutive low-speed impact tests on a bumper system, the influence of the stress softening on the structural performance is studied. Both the experimental and modeling results indicate that the stress softening of the foam cushion compromises to a certain extent the bumper impact performance in subsequent impacts.

1. Introduction

Polymeric foams such as expanded polypropylene (EPP) and polyurethane (PU) are often used in protective devices for managing impact loading. The material selection and the structural design are mainly based on the knowledge from single compressive loading test of raw foam materials. However, in actual services, the foam components could be reloaded for several times. For example, the foam cushion, located on the front of the transversal bumper beam to serve as an impact energy-absorption component, could almost fully recover in shape after a low-speed impact or a pedestrian-to-vehicle impact, and then often be reused without any treatment. For the reuse, it is assumed that, besides its shape, the energy-absorption capability of the foam cushion is recovered as well. However, the foam material behavior may not meet this expectation.

The mechanical behavior of polymeric foams under the uniaxial compression has been extensively reported in literatures [1–3]. As pointed out by Lu and Yu [3], after the initial linear elastic stage, the stress of foams exhibits almost a plateau level in a large strain range and can be enhanced with the increasing strain rate. The plateau characteristic of the foams' stress–strain behavior offers structural designs the possibility to maintain a proper force level in a relatively large deformation range in crash events for the purpose of energy-absorption. However, the reused foam components could not provide the originally designed energy-absorption function after multiple compression cycles. In fact, a stress softening effect of polymeric foams has been revealed in papers [4–8]. Xia et al. [9] reported the result of the uniaxial compression test with loading–unloading cycles of EPP foam samples. It is indicated that, to achieve the same deformation, a significantly lower force is resulted in the subsequent compressions than that in the first compression, so the energy-absorption capability is significantly reduced after the foam sample experiences the first loading–unloading cycle.

Researchers have taken efforts to describe the mechanical response of polymeric foams under different loading environments [1,10–19]. Gibson and Ashby [1] have well documented the material constitutive models for polymeric foams. Some were on the basis of the empirical models [10–14]. The failure surface of rigid foam under multi-axial loadings has been proposed by Gibson et al. [11] and Triantillou et al. [12]. Puso and Govindjee [13] presented a visco-plasticity model by extending the works of Gibson et al. On the other hand, some constitutive models were based on the material nature, i.e., the three-dimensional periodic cell structure of foams [15–19]. Various empirical models for polymeric foams have been embedded into the finite-element (FE) software, e.g., ABAQUS, LS-DYNA, PAM-CRASH. For instance, material model HYPERFOAM in ABAQUS is according to the works by Storakers [14], in which the material parameters can be identified by different types of tests. However, the material models based on the micro-structures of foams can be hardly found in the existing commercial FE software codes.

There are few works of modeling the stress softening effect of foams in the literatures. However, similar stress softening phenomenon of rubber-like materials, referred to as the Mullins effect,

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