MECHANICAL PROPERTIES OF AUXETIC PVC FOAM UNDER CYCLIC LOAD

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Abstract

In this paper the mechanical behavior of an auxetic PVC foam under different cyclic loadings are presented. We show that the hysteresis loop reverses itself and then reverses again during the initial cycles. A possible explanation for this usual phenomenon is offered.

1 General Introduction

The Auxetic foam with negative Poisson's ratio has many advantages over conventional foam due to its auxeticity. It has a higher shear modulus, better indentation/impact/fatigue resistance and better noise absorption. The main purpose of this research is to manufacture and characterize different types of auxetic foams to be used as the core layer material for sandwich panels. In this paper, results are presented from cyclic loading tests on a number of specimens with both the auxetic foam and conventional foam. At the earlier loading stage of the auxetic foam, the stress-strain loop is counterclockwise and then it turns into clockwise in the later stage. On the other hand the stress-strain loop is always clockwise when the same loading history is carried out on the conventional foam. An explanation for the possible cause is presented in discussion section on the basis of the microstructure of the auxetic foam.

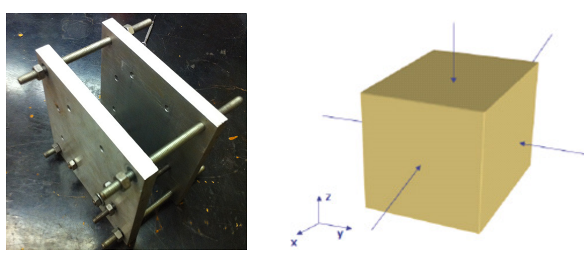


Figure 1. An aluminum mold for compressing the conventional foam triaxially

2 Technical Methods

2.1 Manufacture of the Auxetic Foam

The A conventional PVC cubic foam sample with its size being 75mm×75mm×75mm was first cut from a large block. The characteristics of the foam are: size of the foam cell is about 50 μm, the tensile strength is about 0.6 MPa, Young's modulus is 90MPa, and the density is 44.3kg /m3. It was then converted into an auxetic foam by the following steps: (1) compressing the foam in three dimensions sequentially by clamped it in an aluminum mold (Fig 1); (2) placing the aluminum mold with the sample inside an oven and heated to about

135^{o}C and kept at that temperature for about 15~30 minutes; (3) the aluminum mold was then allowed to cool down to room temperature (23^{o}C) and the resulting foam became auxetic. Detailed micrographs of the conventional and auxetic foams are shown in Fig 2.

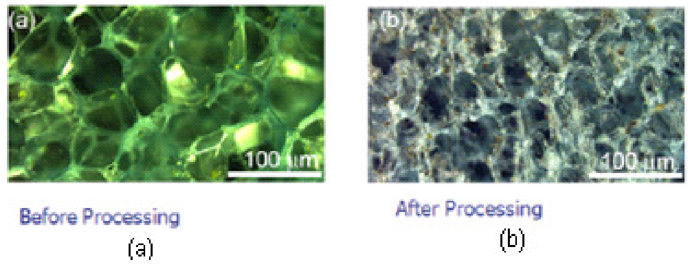


Figure 2. Cell image of foam material (a) before processing, (b) after processing

2.1 Digital Speckle Photography (DSP)

DSP is the technique we use to analyze the deformation pattern of the specimens. The basic procedures of the DSP are described as follows. By recording the speckle pattern (which is nothing but the textural appearance of the foam cells) at different stages of loading and "comparing them" through an algorithm called CASI (Computer Aided Speckle Interferometry), displacement vectors at every "point" of the specimen are obtained through which the strain fields are calculated. The resolution of the technique is a function of the size of the speckles and the resolution of the recording device. For macro specimens with an optical recording system, speckle size of the order of 20µm or larger are commonly used. For smaller specimens either micrometer size or nanometer size speckles are employed.

3 Specimens and Test Procedure

The specimens used for the cyclic loading study was cut from a single cubic auxetic foam block manufactured according to the procedures previously described. The size of the specimen was about 65mm×10mm×7mm (Fig 3). The specimen was clamped at both ends and the viewing area was only 15.5mm in length in the middle so as to avoid end effects. The specimen was mounted into a microtester that can apply cyclic loading. The specimens were tested first and then analyzed by DSP. A VHX-100 digital optical microscope (Fig 4) was used to record the speckle pattern as the load was being applied quasi-statically by a servo controlled microtester (Fig 4) at a constant rate 2mm/min.

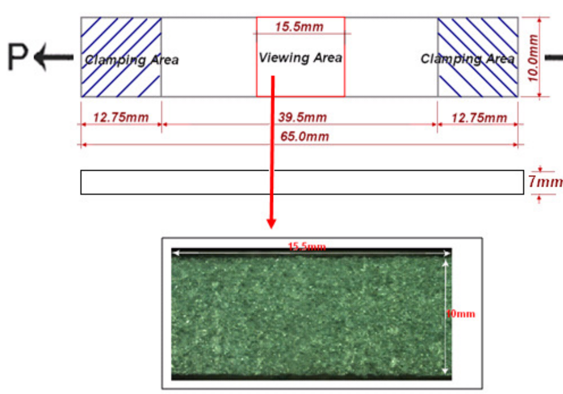


Figure 3. Coupon specimen of uniaxial testing and its viewing area under microscopy

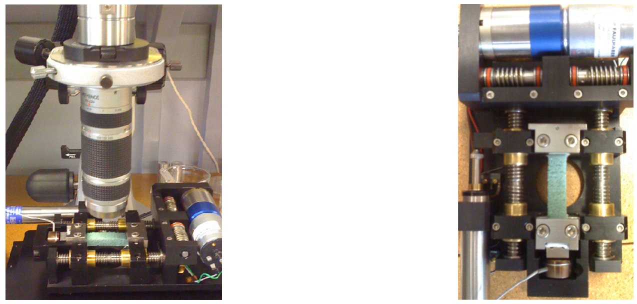


Figure 4. VHX-100 digital optical microscope (left) and servo controlled microtester (right)

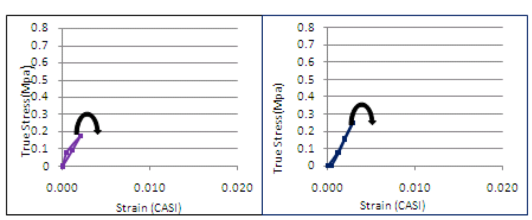
The VHX-100 digital optical microscope can record the entire loading process. The full video was captured and separated into single images by VirtualDub. Typically only some of them were selected for analysis. The values of load can be read directly from the servo controlled microtester, and the cross section area of the specimen in the viewing area can be measured and calculated by Photoshop software. That is how the true stress was obtained.

4 Results and Discussion

The Cyclic loading tests were performed on a number of auxetic foam specimens. The specimen underwent the following loading history: in the first cycle, the load started from 0, to the maximum value of 10N, and then went back to 0; in the second cycle, the load started from 0, to the maximum value of 15N, and then went back to 0. The next four cyclic loading, each increment of the maximum value was 5N, progressively.

At earlier stages of loading the path of the loop of auxetic foam is counterclockwise whereas at the later stage the loop becomes clockwise as shown in Fig 5. This is a rather interesting phenomenon that was not expected. For comparison we performed the same experiment on the original (i.e. with positive Poisson's ratio) foam. For easier comparison we performed another test on an auxetic foam with the same loading history. All the results are shown in Fig.5.

The stress-strain loop of an auxetic foam is quite unusual. For a conventional material, the clockwise path of the stress-strain loop is easily explainable. Upon loading the energy is stored in the materials. Upon unloading the energy is recovered, but not 100% due to internal friction. In the case of the auxetic foam, however the results indicate that at the early stage the energy recovered is larger than the energy provided. One plausibly explanation for this phenomenon maybe attributable to the fact that the original open foam cell is now converted into cells with reentrant corners. There is a fair amount of residual strain stored inside the auxetic foam. And this residual strain contributes to the energy dissipation of the cyclic loading process. Upon further loading, the reentrant corners are straightened out, thus the material is essentially converted into an ordinary material. As a result, the clockwise loop prevails.



(a) (b)

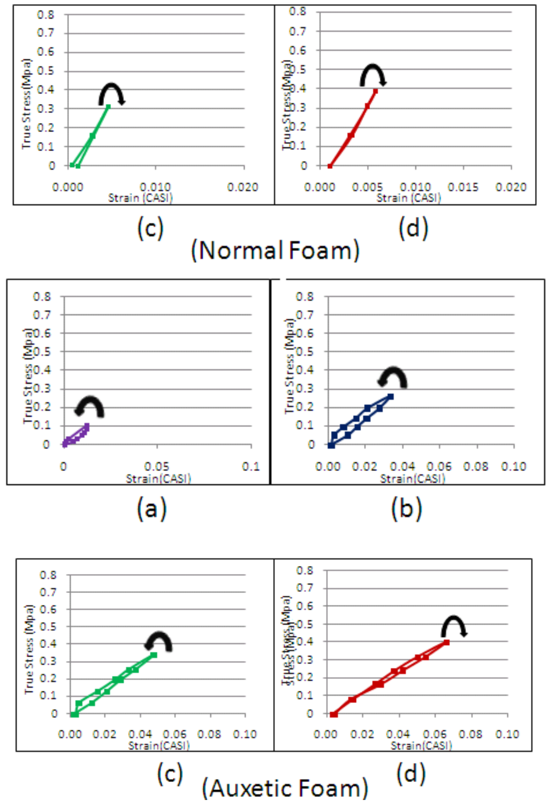


Figure 5. Stress-strain loop of the normal and auxetic foam (a) Loading force from 0-5N-0; (b) Loading force from 0-15N-0; (c) Loading force from 0-20N-0; (d) Loading force from 0-25N-0

The energy dissipation value as a function of applied strain also was plotted as shown in Fig 6. Conclusion can be drawn that the higher auxeticity, the higher energy it can store.

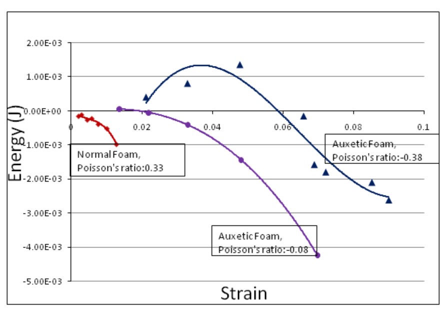


Figure 6. Energy Dissipation of Normal Foam and Auxetic Foam

Fatigue tests were also conducted via the cyclic loading history so as to determine how the negative Poisson's ratio affects the life span of the auxetic foam. The size of the specimens used was the same as in the previous tests. The specimen was mounted onto the microtester, the loading speed was 2mm/min, and the experiments were not stopped until the specimen was broken. The stiffness degradation with the increase of loading cycle for two different Poisson's ratio's specimen is shown in Fig 7.

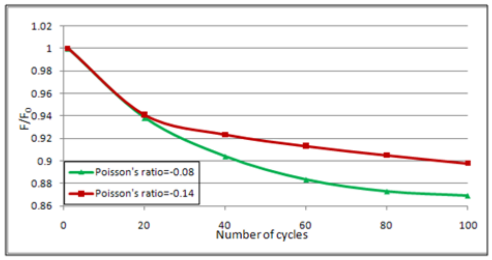


Figure 7. Stiffness degradation with increase of loading cycles with different Poisson's ratios

In Fig 7, F0 is the maximum load F obtained in the first cycle and F is maximum load obtained in the N cycle. Finally the auxetic foam was broken with the average number of cycle being 920 with a range varying from 810 to 1180 (Fig 8), In contrast the conventional foam broke broken with average number of cycle being 360 with a range varying from 230 to 430. The comparison shows that the auxetic foam has a higher resilience when subjected to cyclic loadings over the conventional foam.

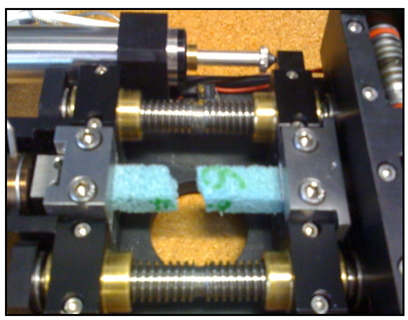


Figure 8. Auxetic specimen broken with number of cycle 920

4 Summary

In this section, conventional PVC foam has been successfully converted into auxetic foam via triaxial compression and heat treatment. The degree of auxeticity as a function of volume reduction was investigated as well: the higher the volume reduction, the larger the negative Poisson's effect is. Auxeticity materializes only after the volume reduction exceeds 50% approximately. In this investigation we presented the results of auxetic foam under cyclic loading.

Some interesting results on the stress-strain loops are found and analyzed. For conventional foam, upon loading the energy is stored in the materials, upon unloading the energy is recovered, but not 100% due to internal friction. The path of the stress-strain loop is clockwise. For auxetic foam, at the early stage the energy recovered is larger than the energy provided. One plausibly explanation for this phenomenon maybe attributed to the fact that the original open foam cell is now converted into cells with re-entrant microstructures, which renders residual strain to be stored inside the auxetic foam. And this residual strain effects the energy dissipation process of the cyclic loading.

Upon the fatigue test under cyclic loading, for a prescribed strain, the stiffness of auxetic foam degrades when the number of cycles increases. Compared with the conventional foam, the auxetic foam shows higher resilience towards fatigue resulting in potential higher life-span.

Acknowledgement

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