STATIC AND DYNAMIC FAILURE AND FRACTURE BEHAVIOR OF POLYMER FOAM CORE

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1 Introduction

Polymer foams have shown promise as a core material for sandwich structures in marine craft due to their high energy absorption capabilities, especially in the case of impact loading [1,2]. There are well documented studies on the compressive properties and energy absorbing behavior of these materials [3]. It is shown that the structural response of polymer foam strongly depends on the foam density, cell microstructure and solid polymer properties [3]. There exist a few studies on the tensile properties of open and closed cell foams with a presence of notches and holes [4-6]. Besides these few studies presented in literature, the effect of holes, cracks and notches in foam materials is not well understood. A detailed investigation on the failure of polymer foam and the effect of hole and cracks on the tensile strength of this material is essential. It is also observed that, foam cracking is one of the main failure modes in sandwich structures. Usually, in sandwich structures, the cracks starts at the core material and propagates to the faces and results in delimitation. Understanding the fracture properties this material is important.

In this paper, an experimental investigation on the tensile properties of Corcell foam with a presence of crack, notches and holes is presented. Furthermore, a fracture behavior of this material is investigated. An INSRON tensile testing machine in conjunction with a 2D digital image correlation (DIC) technique is used. It is observed that the net section tensile yield strength in the presence of holes, notches and cracks is higher than that of the intact specimen. It is also observed that, the defected specimen failed at a lower strain compared to the intact specimen, indicating a presence of a strain concentration around the defects section.

2 Material and Specimen Geometry

2.1 Material

The core materials used in the present study were Corecell™ A series styrene foams, which were manufactured by Gurit SP Technologies for marine sandwich composite applications. The material properties for A800 and A1200 Corecell™ foam that are used in the present study is shown in Table 1.

Table 1. Selected mechanical properties of foam

Material	Nominal density (kg/m3)	Shear modulus (MPa)	Shear Elongation (%)
A800	150	47	50
A1200	210	76	46

2.2 Specimen geometry and dimensions

Four different specimen geometries were considered: dog-bone specimens without defect (DB), with a center crack (CC), with an edge crack (EC) and with a center hole (CH). To avoid the size effect, the net cross sectional area were kept constant for all the specimens considered. The gage lengths were 140 mm, effective widths were 12 mm, and thicknesses were 6 mm. For the fracture experiment, single edge notched bend (SENB) specimens were prepared from A1200 foam sheet. The span length was 245 mm, the width was w= 50.4 mm, the thickness was B=25.4 mm and the initial crack length was a= 20 mm. The crack was first machined with 1 mm thick blade and later the artificial crack was extended with razor blade.

3 Experimental Procedures

3.1 Tensile Strength

An Instron machine was used with a displacement control mode at a speed of 1 mm/min and the tensile load was recorded directly by the load cell. To measure the strain fields around the required area, a 2D digital image correlation (DIC) technique was used. First, the displacement and strain field around the gage length were calculated and later the strains on the required field were extracted. The same procedure was followed for all specimen geometries.

3.2 Fracture Behavior

The fracture surfaces of tensile specimens of the polymer foam considered in this study show no evidence of gross yielding or necking. Hence the foam is relatively brittle and stress intensity factor was used as a parameter to determine the fracture behavior. There are different techniques developed for determining the stress intensity factors for brittle materials. In the present study, the stress intensity factor K_I was obtained experimentally using a three point single notched bending experiment. An INSTRON machine was used in a displacement control mode at a cross head speed of 1mm/min and the load-displacement data was recorded directly by the load cell. Digital images of the sample at several deformation steps were taken using a high speed CCD camera. A 2D DIC technique was used to obtain the displacement and strain fields. The stress intensity factor K_I was calculated using three different techniques; critical load in the load-displacement curve using the linear elastic fracture mechanics theory presented by Eq.(1), the stress intensity factor formulation using a single strain data point with a three parameter solution described by Dally and Sanford [7] and the modified multipoint strain method presented by Berger and Dally [8].

$$K_I = \frac{PS}{BW^{3/2}}\left[2.9\left(\frac{a}{W}\right)^{1/2} - 4.6\left(\frac{a}{W}\right)^{3/2} + 21.8\left(\frac{a}{W}\right)^{5/2} - 37.6\left(\frac{a}{W}\right)^{7/2} + 38.7\left(\frac{a}{W}\right)^{9/2}\right] \quad \text{Eq(1)}$$

Where P is the critical load, a is the crack length, B is the thickness, W is the width, and S is the span.

4 Results and Discussions

4.1 Tensile Strength

The measured tensile load was used to calculate the tensile strength and the average of strains along the defect section obtained from the DIC was used to calculate the corresponding strain. The net section strength, in the case of a specimen with sharp cracks, a notch and a hole, is defined as the tensile load divided by the remaining intact area in the section with the defect.

A typical stress-strain curve for dog-bone specimen is plotted in Fig. 1.

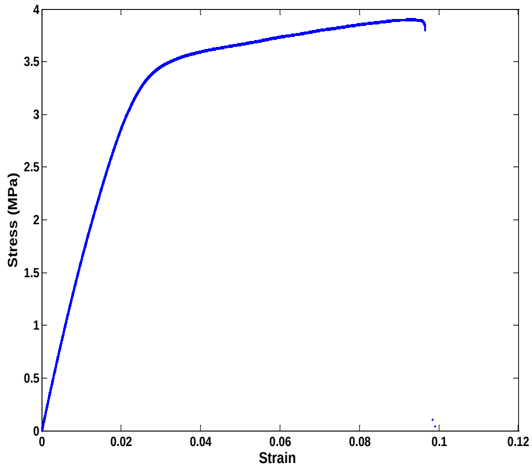


Fig 1. Stress-strain plot for Foam A 800

The above plot shows a typical strain-stress plot of polymer foam, namely, yielding followed by hardening and failure. In the case of specimens with defects, the failure takes place in a brittle manner before any hardening is observed. It is also observed that, the specimens with defects show a higher net section- strength compared to the intact specimen as shown in Fig 2. This could be due to the relocation of failure from the weak plane in the case of cracks with defects. On the other hand the failure strain decrease in the case of specimen with defects compared to specimen without defect as shown in Fig 3.

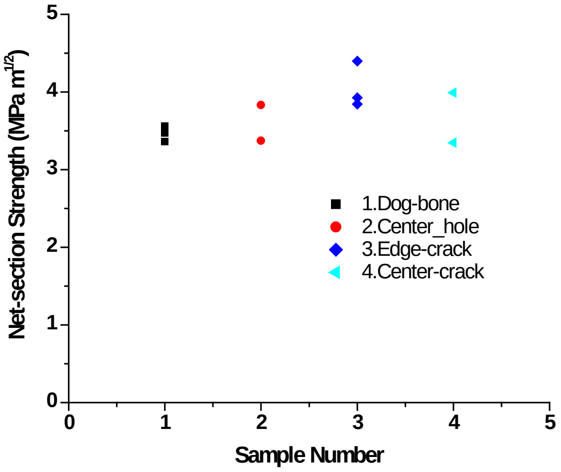


Fig 2. Net-section strength for different type of geometry for A 800 foam

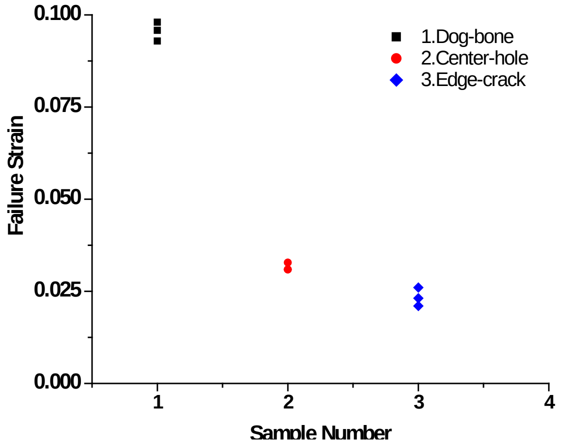


Fig 3. Failure strain for different type of geometry for A 800 foam

4.2 Stress Intensity Factor

A typical load - deflection curve obtained from SENB experiment is plotted in Fig. 4. The stress intensity factor was calculated using Eq. 1 and the critical load from the load-deflection curve. The average value of KI obtained from the critical load measurement is 0.55 MPa m1/2 with in an error of - 0.011 to + 0.028.

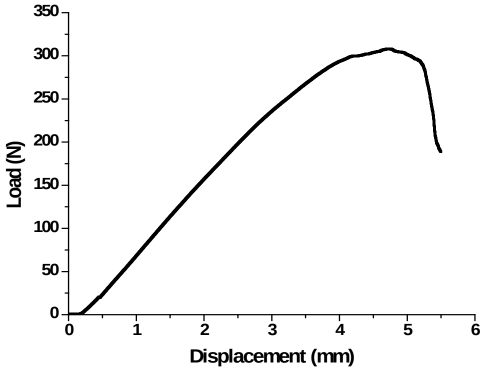


Fig 4. Load displacement for three point bend specimen of A1200 foam

On the other hand, the displacement and strain fields around the crack tip were calculated from the acquired image using vic2D commercial software. Fig. 5 shows a typical spackled pattern of three-point bend testing specimen, and Fig. 6 shows the strain contour around the crack before the crack propagates. This strain date was used to calculate stress intensity factor using the single point strain gage method.

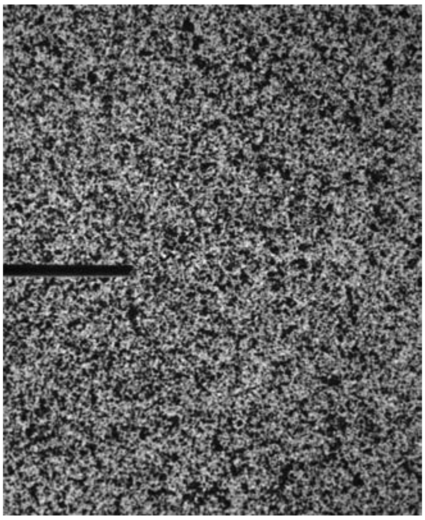


Fig 5. A typical spackled pattern of three point bend specimen

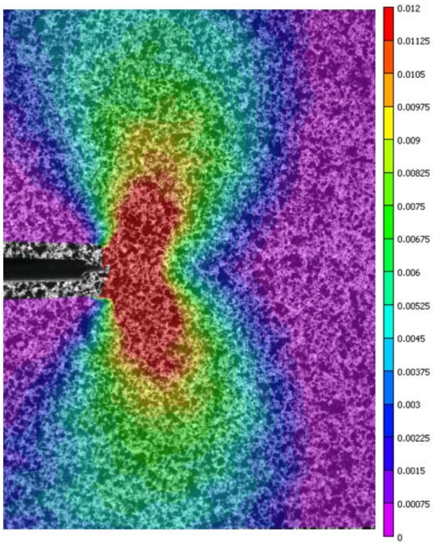


Fig 6. A typical strain field near the crack tip obtained using DIC

In the case of a single point strain gage method, the position of the strain gage θ and the orientation of the gage α are a function of poison's ratio. The Poison's ratio for the A1200 foam material is 0.22 and results in α =64.68 and θ =78.65. Using these two angles, multiple points at different radius were considered and used to calculate the stress intensity factor [7]. The stress intensity factor as a function of distance from the crack-tip (r) for A1200 foam is presented in Fig.7. In the region where the first term is dominant but outside the non-linear crack-tip region, a repeatable result was obtained. On the other hand, in the region near to the crack tip and far away from the region where the first term is dominated, the result underestimates the value of K_I. Later it was found that, the plastic zone for this geometry and material is about 3mm and the region between r =3 mm to 9 mm gives an acceptable result for mode I stress intensity factor. As it is shown in the figure, the average fracture initiation toughness is about 0.53 MPa $m^{1/2}$.

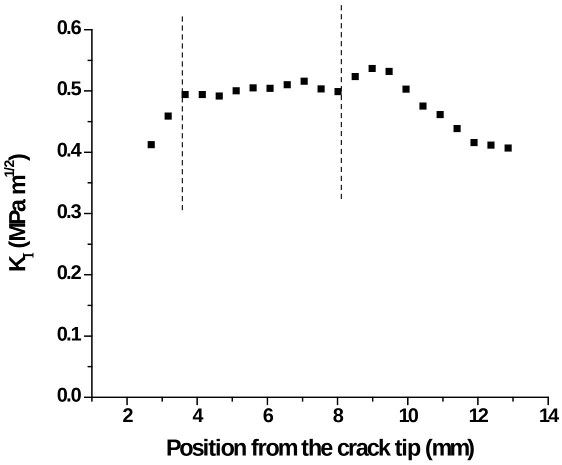


Fig 7. K_{IC} determined from a single point data using three term solution

The modified multipoint strain method presented by Berger and Dally Eq. 7 was also used to calculate the stress intensity factor. The value of K_I is very close to the one obtained in the above two cases, with average value of K_I =0.53 MPa $m^{1/2}$. Using the calculated stress intensity factor and constants, the strain field was regenerated as shown in Fig. 8. It is clearly seen that, the strain field, e_{yy} regenerated from the calculated K_I is well matches with the original strain field directly obtained from the DIC Fig.6.

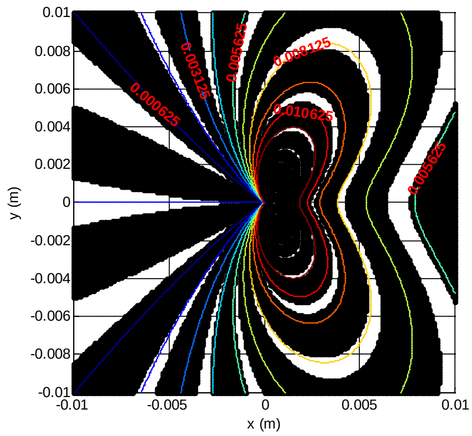


Fig 8 Opening mode strain field regenerated from calculated K_I and corresponding coefficients

4.3 Dynamic Stress Intensity Factor

A modified Split Hopkinson bar apparatus with three-point bed specimen is used to study the dynamic stress intensity factor of A800 and A1200 Corecell foam. Due to the low impedance nature of the material, a polycarbonate bar is used. A detail studies on the use of viscoelastic split Hopkins bar can be found in the literature [8]. In the current study, a 1.8 m long polycarbonate incident bar was placed against a three point bed specimen. Two, diametrically opposite, semiconductor strain gages were mounted in the middle of that bar. A polycarbonate striker projectile was propelled towards the incident bat using an air gas gun. The incident and reflected strain data was recorded using a semiconductor strain gages that were connected with Vishay 2301A signal-conditioning amplifier and an oscilloscope. The load history at the specimen/bar interface was obtained from the recorded incident and reflected strain data using method of characterization. A typical incident and reflected force history at the specimen/bar interface is shown in Fig 9.

In order to avoid the transient effects all dynamic experiments were conducted at a striker speed less than 1.0 m/s. When the time of fracture is sufficiently long, the dynamic stress intensity factor can be calculated from the input load using Eq. 2[9].

$$K_I = \frac{F(t)}{B\sqrt{W}} f\left(\frac{a}{W}\right) \qquad \text{Eq. (2)}$$

where K_I is the stress intensity factor, B the specimen thickness, W the specimen width, a the initial crack length and f(a/W) is the geometric factor.

The dynamic stress intensity factor for the two specimens, Corcell A800 and A1200 foam, as a function of initial crack length is presented in Fig 10. The higher density foam, A1200, shows a higher stress intensity factor.

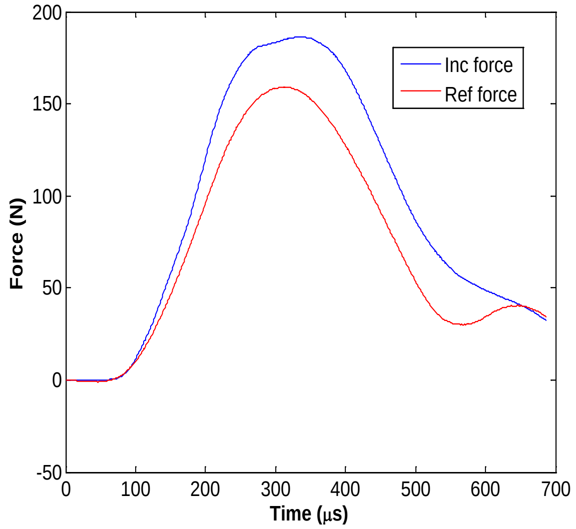


Fig 9 Typical Incident and reflected load history at specimen/bar interface

The quasi-static and dynamic stress intensity factors for both specimens considered are presented in Fig 11. It is observed that the dynamic stress intensity factor is lower than the quasi-static stress intensity factor.

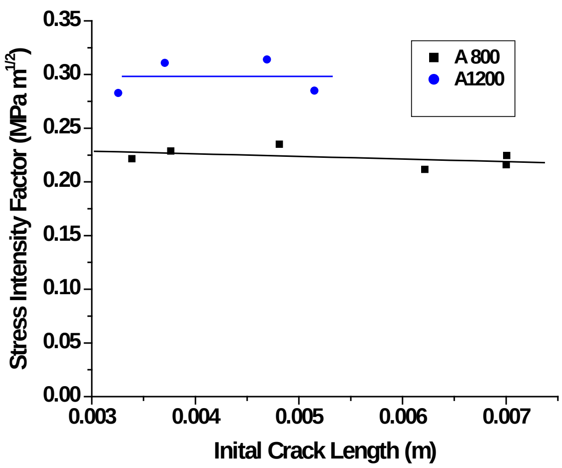
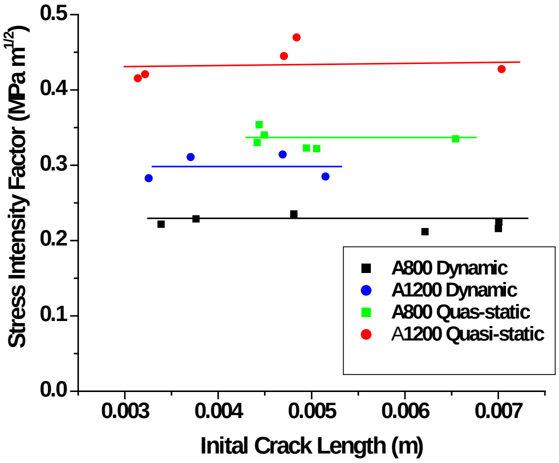


Fig 10 Dynamic stress intensity factor as a function of crack length



5 Summary

An experimental investigation on the effects of holes, cracks and notches on tensile strength of polymer foam was performed. In the case of specimen with cracks, notches and circular holes, a notch-strengthening effect was observed. The net-section strength is higher compared with the specimen without defects. However it was observed that, the specimen failed at a lower strain compared with the intact specimen, indicating a presence of a strain concentration around the defects sections. Fracture experiments have been performed over a wide range of loading rates. It was observed that the dynamic stress intensity factor was lower than the quasi-static stress intensity factor for both the specimens considered.

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