Determination of Traction separation curve in Shear mode using EWF approach for polycarbonate

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Abstract

This paper presents the new test methodology to measure the fracture toughness of the polycarbonate material and also predict the Traction-separation Law when it its subjected to in-plane(shear)mode. The new test method uses an idea of Isopescu test device to apply the shear loading to the specimen and determine the fracture toughens of the material using essential work of fracture concept in shear mode loading. The thickness of the sheet is 1.5mm and the ligament ranges from 6mm to 10mm with regular interval of 1mm.The test results shows that the energy require to break the material in shear mode is 21.40Nmm which is little bit more than the mode I fracture toughness. This study concludes that the new test method has a good potential for evaluation of mode II fracture toughness for polymer materials, still further study by making the groove on the specimen to prove pure shear mode fracture.

Keywords : Shear mode, EWF, Traction separation curve.

1.Introduction

Fracture toughness is called as a amount of resistance which has long been assessed for the polymeric things using the concepts such as energy release rate(G_{c}), stress intensity factor(K_c) and the J-integral(J_c) etc. Also the test methods established using these concepts are based on the linier elastic fracture mechanics (LEFM) approach, which is initially developed for a brittle material. In wide-ranging, all this test used to study the fracture toughness in mode I, current methods have difficulties in measuring the fracture toughness in mode II because of the suitable setup issues. The reason is that, as Williams [1] stated, most polymers have much lower toughness in mode I(opening mode) than mode II(shear mode).Since all the conservative studies are not suitable to measure the fracture toughness in shear mode (mode II),especially for the ductile materials, no investigational data are available to support the above statement.

A new test methodolgy based on thought of essential work of fracture (EWF)[2] was proposed to considered the fracture toughness of a ductile material in opening mode. The EWF concept firstly proposed by the Brogberg [3,4],and has been accepted broadly as a means to quantity fracture toughness of ductile materials. Till now all the studies have been incomplete to measure the toughness of mode I [5,6],and for some special cases of mode III(tearing mode),the EWF study for the is yet leftovers to show the fracture toughness in shear mode due to lack of testing setup.

The purpose of this study is to establish a new test methodology, based on essential work of fracture notion, to quantify the fracture toughness of polymeric materials in shear, mode(mode II) .This method uses an Iosipescu loading to apply shear force[7,8]in the middle section of the specimen. DENT Shear specimen was chosen its transiting deformation behaviour.

This paper grants an approach for measuring mode II fracture toughness of DENT shear specimen. This paper provides a brief review of relevant fracture and associates the fracture toughness of DENT in opening mode with DENT in shear mode.

2.Reviews of EWF test for shear fracture

Essential work of fracture is a new concept for determining the energy consumption which is directly related to the crack propagation process (Cotterell and Reddel 1997,Mai and cotterell 1986 and Karger-Kocsis 1998).Generally the Double-edge-notch-tension test is the most popular method to determine the fracture toughness of a material in opening mode (mode I)condition.Genrally,double-edge-notch-tension(DENT) as shown in fig1. is most used method based on EWF concept for influential the energy consumed in mode I, which is called as specific work of fracture in mode I (w_e^I).here, the value of w_e^I signifies the energy consumed in the fracture process zone for unit area of crack growth.

The data and analysis widely adopted for the DENT specimen is to use the following relationship for the energy ingesting to determine the material toughness,

Specific essential work of fracture(w_e^I),

$$w_f^I = w_e^I + \beta_p^I w_p^I L_0 \quad (1)$$

where the superscript I represents mode I deformation, w_f^I is the specific work of fracture, w_p^I represents the energy of the plastic zone, β_p^I characterizes the shape factor of the plastic deformation zone,and L_o is the original ligament length. Expression 1 suggest that w_f^I,specific work of fracture is a grouping of essential work of fracture and non-essential work of fracture(i.e plastic zone) and also propose that the w_e^I value can be determined by the linier regression of w_f^I values to zero ligament length.Pardoen et al(2004)[9] projected that w_e^I is a combination of real specific work of fracture which is independent of specimen thickness and specific necking energy that is proportional to specimen thickness.

The generalized expression of Eq.(1),

$$w_f^I(L_0,t_0) = \rho_0^I + \beta_n^I w_n^I t_0 + \beta_p^I w_p^I L_0 \quad (2)$$

where,ρ_0^I is mode I essential work of fracture that is independent of the thickness of specimen and w_n^I average work density.

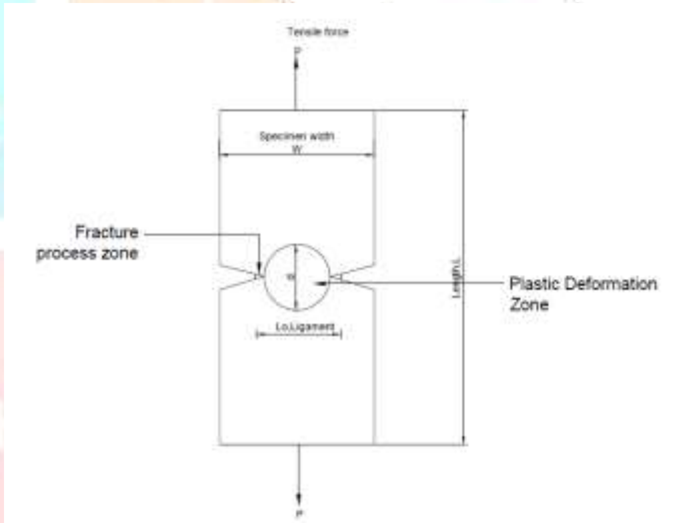


Fig 1. Double-edge-notch-tensile specimen for mode I

In 2005,kwon and Jar, proposed the double-edge-notch-tension specimen as shown in fig2. can also use as a shear specimen by applying Ionescu test, expression for the specific work of fracture,w^{II}_f has been suggested by (kwon and jar,2005).

$$w_f^{II} = w_e^{II} + \beta_p^{II} w_p^{II} t_0 \quad (3)$$

where, superscript II represents the mode II fracture deformation, w_e^{II} essential work of fracture,w_p^{II} average plastic work density, β_p^{II} denotes the shape factor for mode II deformation zone, here the above expression advise that w_f^{II} is dependent on t_o only not on L_o.It is not clear that weather this expression is applicable to polymers or not.Therfore in general, for crack progress in mode II loading, the deformation occurs in both mode,mode I and mode II,

w_f can be expressed as follows,

$$w_f(L_0,t_0) = \rho_0^I + \rho_0^{II} + (\beta_n^I w_n^I + \beta_p^{II} w_p^{II})t_0 + \beta_p^I w_p^I L_0 \quad (4)$$

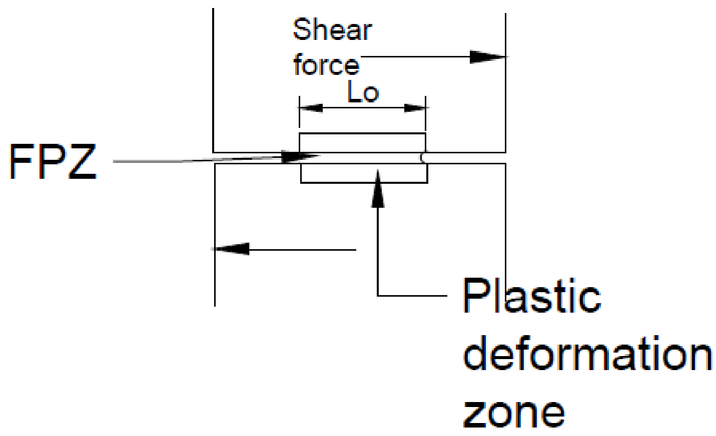


Fig 2. Double-edge-notch-tensile specimen for mode II

3.Experimental details

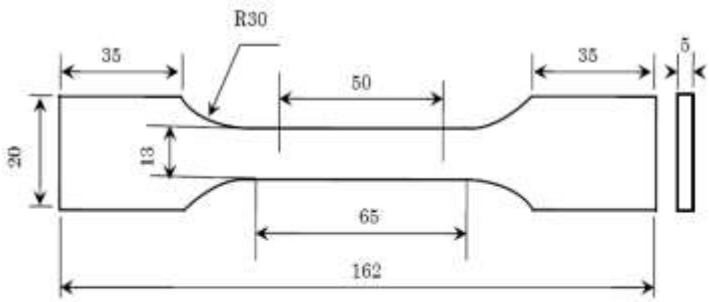
3.1 Experimental setup

Isopescu test was used to apply the shear loading to the DENT specimens. As depicted in fig3.Polycarbonate sheets with the thickness of 1.5mm,1.8mm,2mm,2.8mm were supplied by the Kapoor enterprise Baroda. Specimen for the shear loading were machined from Co_2 laser cut. The ligament ranges from 4mm to 14mm with the thickness of the specimen respectively. The specimen was placed in the Isopescu ring and loaded by tensometer with the loading rate speed of Δ=10mm/min.

Fig3.Experimental setup of Isopescu test

3.2 Mechanical properties

Dogbone specimen were use as shown in fig4., to test the mechanical properties of polycarbonate with the thickness of 1.5mm and the loading rate speed of 10mm/min.



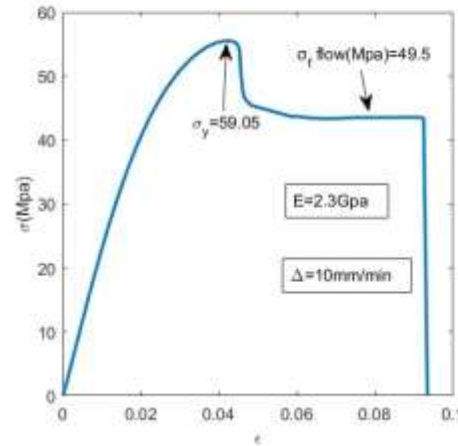


Fig4. (a)Dogbone specimen. (b)stress-strain diagram

After the test with Δ=10mm/min the mechanical properties of the 1.5mm thickness specimen were.

Property	σ_y(Mpa)	$\sigma_{f\ flow}$(Mpa)	ε_y	$\varepsilon_{y\ failure}$	E(Gpa)
Δ=10mm/min	59.05	49.5	0.064	0.106	2.3

4.Results and Discussion

4.1 Isopescu specimen test

(a)

(b)

(c)

Fig5.Crack propagation during the test on the specimen(a)First crack generation, (b)second crack generation, (c)formation of a cylinder during crack growth

At very first when specimen loaded in the Isopescu device, initially the crack developed from the notch tips which is grew in the direction about an angle 25^0 from the centre line connecting to notch tip as shown in fig 5(a). The crack opened up and grew only for a short distance. The second pair of crack were generated near to the notch tip at an angle about 11.3^0 as shown in fig 5(b).now for the further loading the crack grows up in the direction of the generated angle and its development Is around both crack tip as shown in fig 5 (c).As the loading increases due to asymmetric nature of the crack growth, the two cracks resulted into the rolling movement at the and this crack is resulted in to the cylinder whose diameter is proportional to the original ligament length of the specimen.

4.2 Extraction of Traction-separation curve

Above crack development process is also can be reflected in the load-displacement curve as shown in fig6. It shows a load-displacement curve resulted from the specimen with the ligament length 6mm and thickness is 1.5mm which is tested with the loading rate Δ=10mm/min.

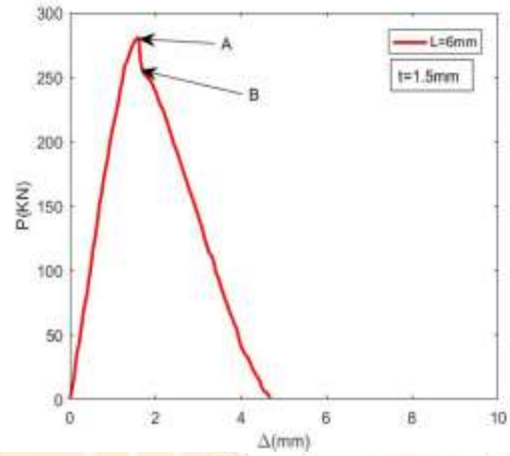


Fig6. Load-displacement curve at Δ=10mm/min.

Point A represents the position where the first pair of crack occurred (Fig.5(a)) and point B indicates the position where second pair of crack (fig(5(b)),Generation of the crack has caused the load-drop ,with the rate of load drop the first pair of crack generated is much faster than the second pair of cracks.The first pair of crack is also "shear-like" crack observed by the Husaini et al.[10].load-displacement curve for the ligament length with the range from

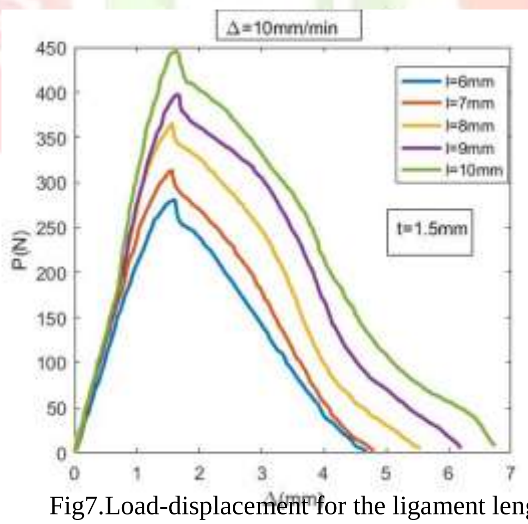


Fig7.Load-displacement for the ligament length 6mm to 10mm

6mm to 10mm is shown in fig7. As an expectation of the EWF theory the load displacement curve is self-similar in nature as shown in fig7.

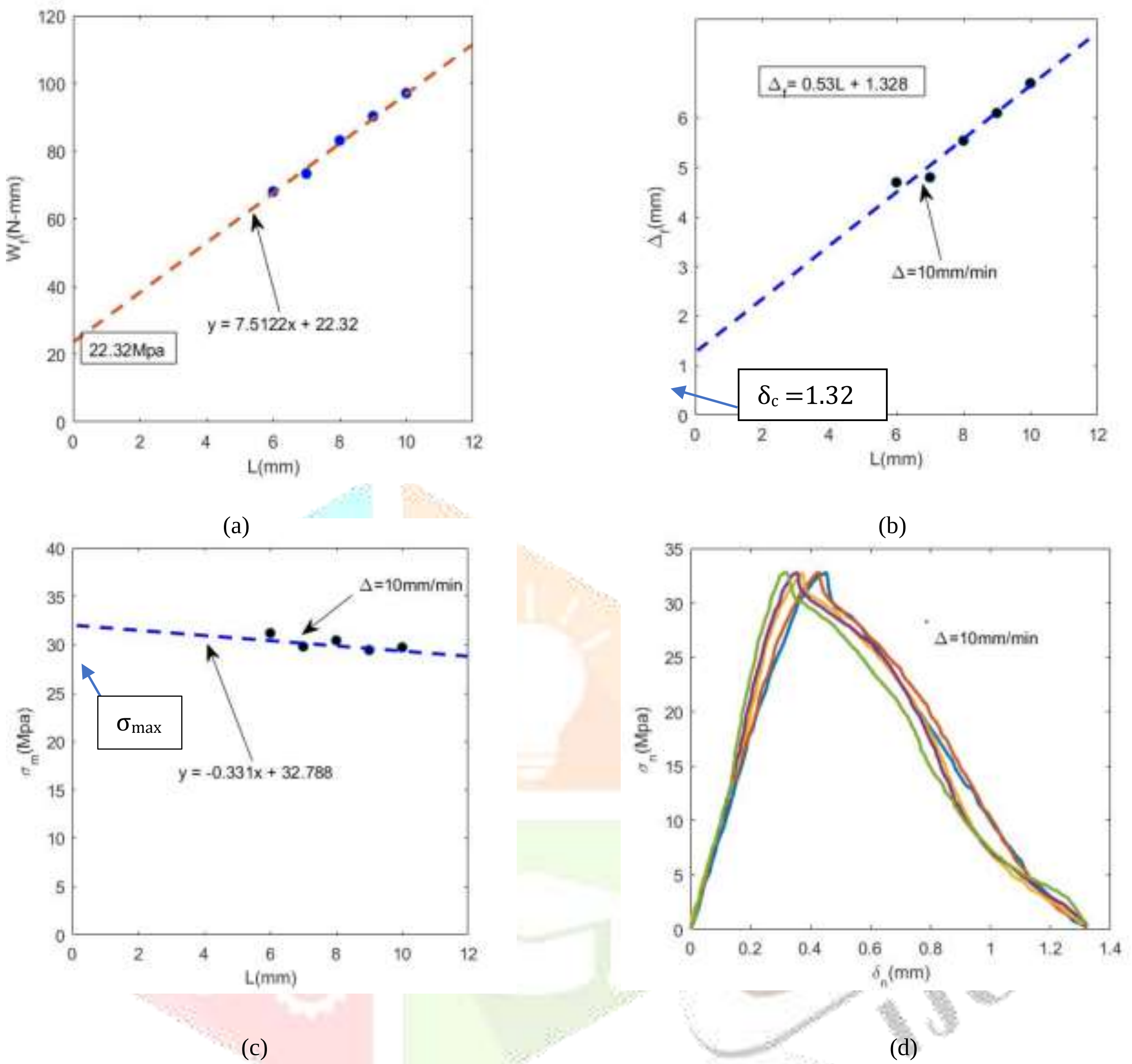


Fig 8. (a)Total specific work of fracture, (b)Displacement at fracture, (c) Net section stress as a function of ligament length, (d)derived traction-separation law

In Figs. 8(a)-(c), the variations of work of fracture w_f, the elongation to failure Δ_f which can be derived from $\Delta_f = \delta_c + \frac{\alpha^c}{2} L$, and σ_{max}=P_{max}/LB with the ligament length has been plotted. It should be noted that the intercept of this all plots are w_e, δ_c and σ^0_{max} respectively. Here last two quantities can be derived from $\sigma_n = \left(\frac{\sigma^0_{max}}{\sigma_{max}}\right) \sigma$,and $\delta_n = \left(\frac{\delta_c}{\Delta_f}\right) \Delta$ for any ligament L it has been shown in fig 8(d). where after all normalisation where done the all the curve collapse into as single curve and this curve now is kwon as a Traction-separation law for a given material and for give mode of fracture.

5.Conclusion

A series of double-edge-notch-tension specimen Isopescu test were conducted to search a new way to determine the essential work of fracture in mode II,w_e^{II}.The test methodology based on Isopescu device using DEN specimen in shear loading is proposed to quantify the energy of the specimen in mode II,w_e^{II}.following conclusion can be made with all this proceed.

The new test methodology yields the w_e^{II} value of 21.40(Nmm) and the displacement 1.32mm for the polycarbonate. Moreover, as the load increases the both crack increasing with an angle of 11.3^0 and then due to asymmetricity the turned into a cylinder in nature and the diameter of that cylinder is proportional to the original ligament of the specimen.Also it can be says that the determined results cannot prove that the shear mode due to crack increasing nature is angular.

Further studies will be conducted to validate the new test methodology on the measurement of shear mode fracture toughness by making a grooved specimen.

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References

[1] Williams JG. Fracture mechanics of polymers. Chichester, England: Ellis Horwood Limited; 1984 p. 45 and 75.

[2] Cotterell B, Reddel JK. Int J Fract 1977;13:267–77.

[3] Broberg KB. Int J Fract Mech 1968;4:11

[4] Broberg KB. J Mech Phys Solids 1971;19:407–18.

[5]] Cotterell B, Pardoen T, Atkins AG. Eng Fract Mech 2005;72(6):827–48.

[6] Pardoen T, Hachez F, Marchioni B, Blyth PH, Atkins AG. J Mech Phys Solids 2004;52:423–52.

[7] Iosipescu N. J Mater 1967;2(3):537–66.

[8] Sullivan JL, Kao BG, Van Oene H. Exp Mech 1984;223–32.

[9] Pardoen T, Hachez F et al (2004) Mode I fracture of sheet metal. J Mech Phys Solids 52(2):423–452.