Key Engineering Materials
ISSN: 1662-9795, Vol. 851, pp 128-134

Submitted: 2020-01-22
Revised: 2020-02-25
Accepted: 2020-02-27
Online: 2020-07-03

Fracture Propagation Pathways Pattern on UV-Irradiated Double-Edge Cracked of Mordenite Zeolite-HDPE Composites

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Keywords: pathway, fracture, propagation, double-edge-cracked

Abstract. Mechanical failure of zeolite-high density polyethylene (HDPE) material applied to skull bone implants is a material fracture that cannot be controlled. An important step to minimize failure due to fracture is to understand the fracture characteristics indicated by the propagation path pattern. This study aimed to investigate the fracture propagation pathways of zeolite-HDPE composites in quasi-static conditions. UV-irradiated Double-edge cracked zeolite-HDPE composite was tested in mode I (a stress perpendicular to the plane of the crack) in a universal testing machine (UTM) with a crosshead speed of 2 mm/min at a constant room temperature of approximately 25°C. The stress and elongation were registered by the UTM. During loading, the evolution of cracks in the ligament length region was recorded with the camera so that the crack propagation pathway until the total fracture occurs can be clearly observed. The results show that the crack propagation pathway patterns were not all straight and parallel to the ligament length. They are also found in a deviant state of the ligament length line by forming an angle α. created between the ligament length line and the fracture propagation deviation direction. This deviation occurs after the crack propagates straight away from the initial-cracks.

Introduction

Polymer materials are widely applied as biomedical materials including prosthetic materials, bone and dental implants, and tissue engineering. Polymer-based biomaterials provide many advantages compared to ceramics and metals, especially in terms of low prices, ease of production processes in various shape, and the ability to provide mechanical and physical properties as needed. They are also biocompatible with body tissues. High-density polyethylene (HDPE) is a thermoplastic material that has been widely applied in various purposes especially in the biomedical field as implant material [1-3] because it is biocompatible [4,5], non-toxic [6], and resistant to UV radiation [7,8]. In order to improve the mechanical properties of materials, HDPE could be combined with a lot of particle material as a reinforcement. Zeolite-high density polyethylene composites have been widely investigated by Erawati et al. [9], and Purnomo and co-workers [10-13] related to fracture properties and tensile strength. Natural zeolite is a material with a complex structure that causes them difficult to understand, for example, the problem of interaction with HDPE, the size and distribution of aggregates in the host matrix. The interaction between particles - host matrix is an important factor that determines the toughness and behavior of material fractures [14-18].

Description of the fracture process provides clarity about the toughness behavior of material fractures in response to external loads [19,20]. The introduction of the pattern of fracture propagation pathways is important regarding the identification of these behaviors. Minimizing composite mechanical failure can be done by understanding the material characteristics that control fracture resistance. Therefore, it is important to identify the formation of a damage zone through mechanical testing to obtain an overview of the fracture mechanism. Fracture pathway formations describe various information including energy dispersion at the crack tip, damage zones formation, and the effectiveness of crack blunting [21,22].

The behavior of thermoplastic matrix composites can be evaluated through the presence of damage zones that occur around the crack tip. The fracture toughness is marked by the size of the damage zone. This zone of damage appears very clearly in mode I fracture under static quasi conditions. Therefore, it is very important to conduct a study on the pathway patterns of fracture due to mode I-type loading.

Method

Specimens tested were produced from HDPE fille with mordenite type of natural zeolite. Composites were formed using injection molding techniques. Two symmetrical notches were produced with molding injection on thin plate specimens with dimensions of 80 x 50 x 4 mm^3. The initial crack at the notch tip was created using the fresh razor blade so that the ligament length (distance between the two ends of the crack) varies, i.e. 10, 11.5, 13, and 14.5 mm. Furthermore, the specimens were placed in an ultraviolet irradiated room with an intensity of 95 $\mu W/cm^2$ for 200 hours at a constant temperature of 70°C. Double-edge cracked specimens were tested in mode I in quasi-static conditions at Universal Testing Machines (UTM) at room temperature (around 25°C) with a cross head speed of 2 mm/min. The load and displacements were registered by the UTM.

Schematic representations of the double-edge cracked specimens and experimental settings consisting of test specimens on UTM and recording cameras are presented in Fig. 1. The camera was used to record crack propagation until both cracked ends meet each other when loading. The mechanical test was carried out based on the ESIS protocol [23]. The test data was registered by the machine, while the ligament yielding process, crack initiation and propagation are recorded with Sony Handycam and camera. Crack propagation patterns are discussed.

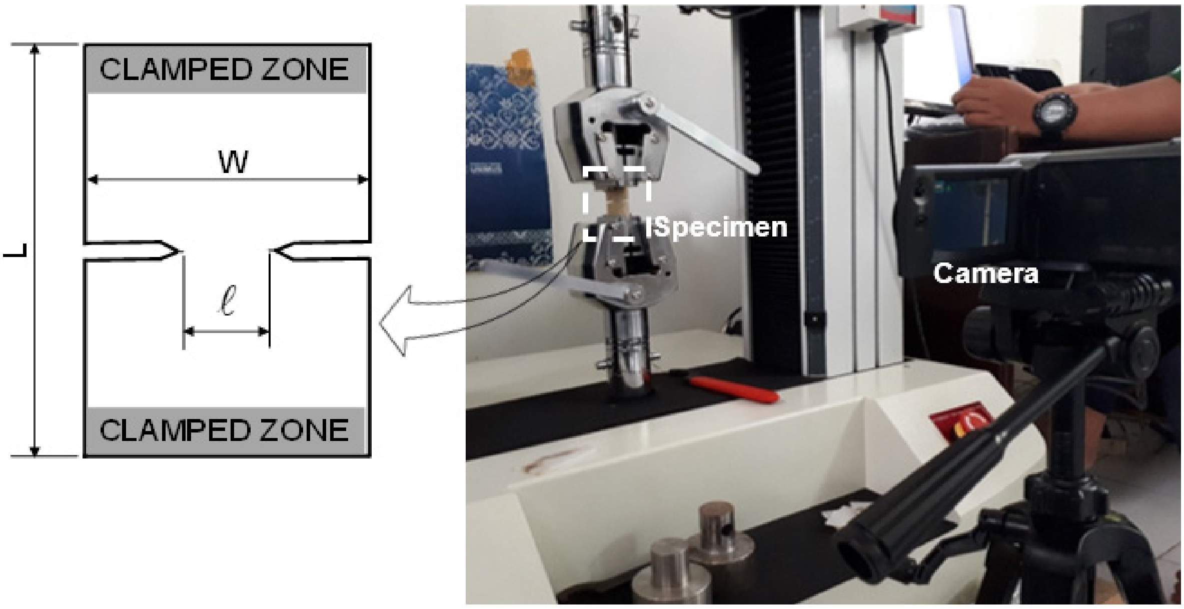


Fig. 1. Experimental arrangement and schematic of spesimen. Where W and L are the width and the specimen length, respectively.

Results and Discussion

The mode I fracture test in double-edge cracked UV-irradiated zeolite-HDPE specimens was completed. Stress - elongation response during loading was shown in Fig. 2. It is clear that all curves have similarities which show that the material behaves the same when the external load is applied. The crack initiation in the sharpened notches occurs in the zone around the curve peak (point A) and the crack propagation ends when both of the crack tips meet in the middle of the ligament length (point B). The end of the crack propagation is marked by a curve that decreases sharply on the part of the broken curve which then reconnects.

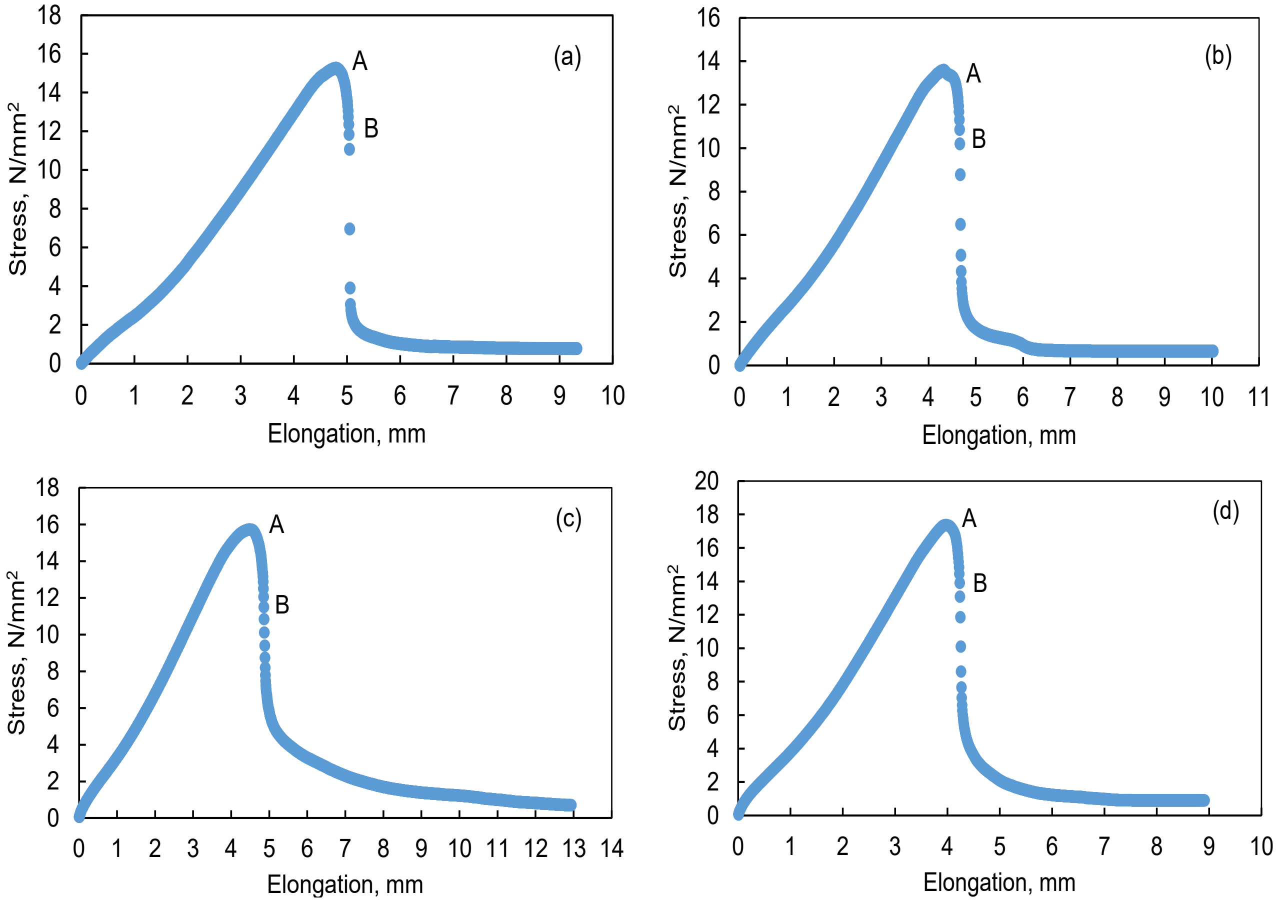


Fig. 2 Stress – elongation response during loading. in the tested specimen with ligament lengths of (a) 10 mm, (b) 11.5 mm, (c) 13 mm, and (d) 14.5 mm. Point A is the occurrence of the initial crack, and B is the end point of the crack propagation i.e. when the two crack-tip meet in the middle of the ligament length.

The phenomenon as shown in Fig. 2 shows that all test specimens are in a state of resilient fracture. In many ductile materials, this type of fracture is followed by the emergence of a damage zone or stress whitened zone. However, Fig. 2 does not show explicitly the pattern of the broken path in the test specimen. This situation is different from the results of research conducted by Awaja et al. [24].

The evolution pattern of all specimens tested during loading is similar even though the ligament length is different. Figure 3 shows the evolution pattern of the cracked region in the ligament length (ℓ = 15 mm). White arrows indicate the direction of increasing elongation material when tested. Evolution began when the load started to be applied and can be classified into three conditions, namely notch sharpened blunting, crack initiation, and crack propagation (see Fig. 3). In the initial stage, the tensile load causes the ligament to experience yielding (3a). After achieving full yielding, cracks are initiated at both tip of the notched sharpened (3c) and the crack extension increases ($a \geq 0$). Cracks propagate rapidly and met in the middle of the ligament length.

In the case of a crack meeting location, not all specimens create a straight propagation pathway cracking on the ligament. Figure 4 shows various patterns of crack paths around the ligament length. The path pattern in Fig. 4a shows almost linear ($\alpha_1 = \alpha_2 = 0$). However, there are specimens tested which fracture paths create a distorted pattern (α_2 and α_2). As a result, the two ends of the crack when reaching the middle of the ligament length are separated by distance H (Fig. 4b). The two ends of the crack then propagate and coalesce after taking the total distance H.

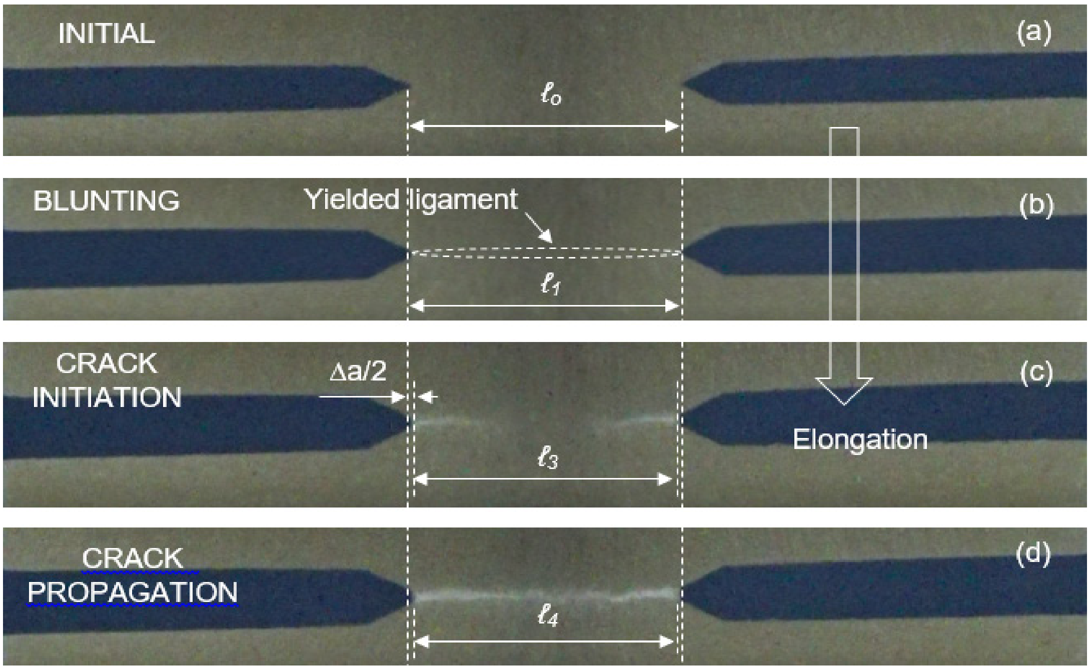


Fig. 3. Evolution of specimen during test. (a) initial loading conditions, (b) blunting at the tip of the notch sharpened, (c) cracks initiated, and (d) crack propagation. White arrows indicate the direction of elongation increase.

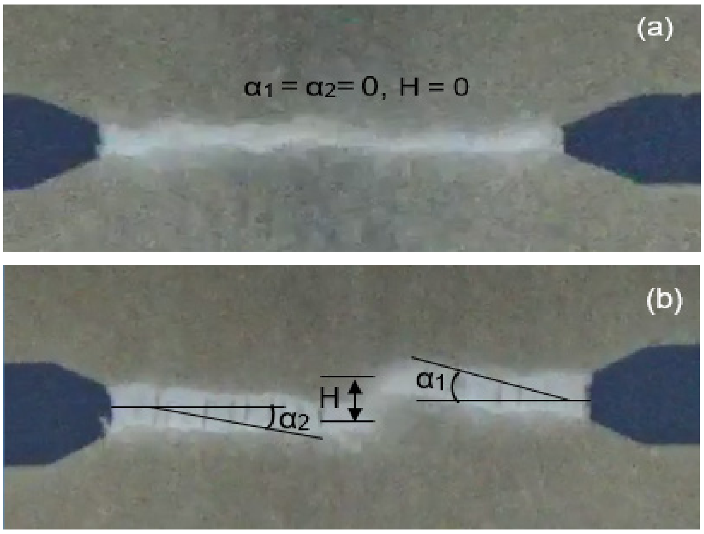
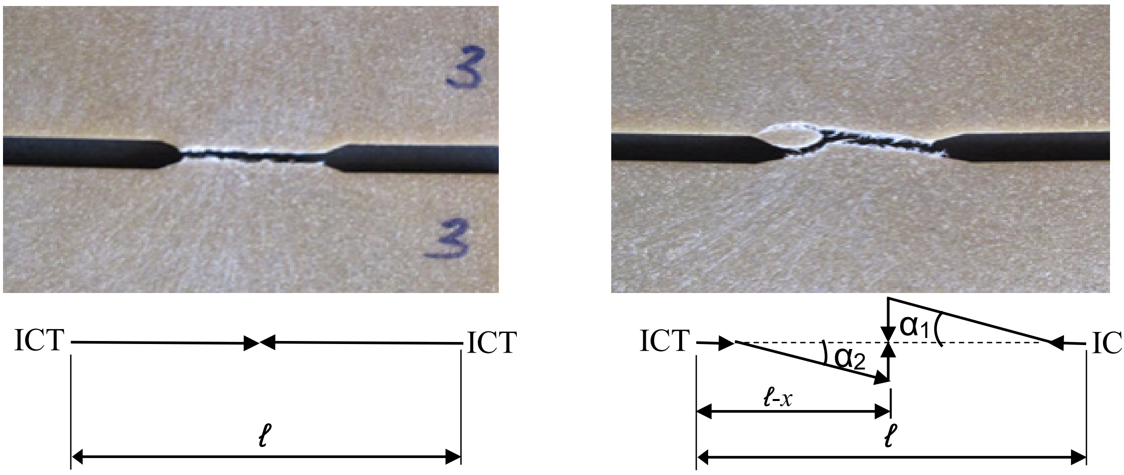


Fig. 4. Pathways pattern of fracture in ligament length consisting of a straight pattern with H = 0 (a), and not straight or a Z pattern with H ≠ 0 (b). The α is the angle created between the ligament length line and the fracture propagation deviation direction, while H is the total length of the deviation from the straight ligament line.

Composites are able to present strong properties depending on the constituent material and the relationship mechanism between them. In relation to the latter mentioned, there is an interface transition zone, ITZ - the region between particles or aggregates of particles and matrices, which are usually weaker where the possibility of aggregate surrounding cracks is high [25].

Composites are able to present strong properties depending on the constituent material and the relationship mechanism between them. In relation to the latter mentioned, there is an interface transition zone, ITZ - the zone between particles or aggregates of particles and matrices, which are usually weaker where the potential of cracks around the aggregate is high. The schematic illustration of crack propagation until the meeting of the two ends is shown in Fig. 5. Cracks start from initial-crack tips (ICT) and propagate in a straight pattern ($\alpha = 0$) on the ligament length path. The existence of ITZ causes the path of propagation of the crack to deviate ($\alpha > 0$). The crack propagation meets in the area between two ICTs with a distance of *x* (Fig. 5b). Actual and schematic illustration of crack propagation pathway are depicted in Fig. 5. This phenomenon is similar to the results of research conducted by other researchers before [24, 26].



(a) (b)

Fig. 5. Actual and schematic illustration of crack propagation pathway with a straight (a) and deviating pattern in ligament length. ICT: initial-crack tip

Conclusions

The crack propagation pathway pattern on the DENT composites has been successfully investigated. There are two main patterns of propagation pathways, those are straight lines and meet in the middle of the length of the ligament, and the second pattern is a slash with a slope α and meets in the middle of the length of the ligament with the distance H between the crack tip. These results are very important in predicting the pattern of subsequent study fracture pathways, especially fractures on thermoplastic-based material filled with particles. The introduction of zeolites as fillers into the HDPE matrix has been shown to provide information about fracture pathway patterns. Further research is needed to understand their role regarding fracture behavior and fracture pathway patterns.

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