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THE EFFECT OF BIAXIAL STATIC LOADS ON CRACK BEHAVIOR IN DIFFERENT COMPOSITE MATERIAL SAMPLES

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Abstract: The study of crack propagation and crack behavior in composite materials is an important issue in fracture mechanics. Compact Tension (CT) specimens are made from three different composite materials' forms, fiberglass/polyester, Kevlar/polyester and Hybrid fiberglass/Kevlar/polyester. The specimens are exposed to uniaxial and biaxial static loads for open time. The crack path tracked until deviation from normal direction of crack occurred. It was remarkable that the effect of the biaxial load decreased the static load life of the fiberglass models about 20.7% and 13.5% for the Kevlar models and 9.8% for the Hybrid ones.

Keywords :*Crack Behavior, Composite Materials, Compact Tension Test*

تأثيرالأحمال الاستاتيكية ثنائية المحور على سلوك الكسر في نماذج من المواد المركبة

الخلاصة: تعتبر مسألة دراسة نشوء الشق و سلوكه من المواضيع المهمة في ميكانيك الكسر. تم تصنيع عينات اختبار (الشد المتراص) وثلاثة تركيبات مختلفة من المواد المركبة، مكونة من الالياف الزجاجية/بولستر، الكفلر/ بولستر و الالياف الهجينة الزجاجية/ الكفلر/بولستر. تم تعريض العينات الى احمال ستاتيكية احادية وثنائية المحور ولفترات زمنية مفتوحة. تم تعقب مسار الشق مع مرور الزمن لحين انحراف الشق عن الاتجاه المستقر. لوحظ ان تأثير الاحمال ثنائية المحور على العينات ادى الى تخفيض عمر التحمل الاستاتيكي لعينة الالياف الزجاجية بنسبة 20.7% وبلغت 13.5% لعينات الكفلر بينما بلغت 9.8% للعينات الهجينة.

1. Introduction

In mechanical applications, composites, due to their high specific strength and stiffness are widely used in structures. Composite structures are designed to hold structural solidity and remain durable for the life service. Cracks are developed in the plies in fiber reinforced composite laminates when they are loaded mechanically or thermally. These cracks lie in the plies along the fibers known as ply cracks, transverse cracks, or matrix cracks.

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In presence of those cracks, laminates respond in different way than in its original state and failure take place because of these directly, they can lead to laminate failure or de-lamination.

For structural health, performing deformational and failure analysis of laminates with ply cracks is very necessary.

There are four main types of failure mechanisms, De-Bonding, Matrix Cracks, De-Lamination and Fiber Breakages. Danai Abhijeet R, et. al. [1] gave a good explanation for these types.

Laminated composite materials are fabricated using plies stacked together providing new materials having superior mechanical properties over constituent parts. The failure process is complex, for both intra-lamina damage and inter-lamina damage mechanisms, the first mechanism is like matrix cracking and fiber fracture, the second mechanism is like delamination between plies or de-bonding between fibers and matrix. In fiber reinforced plastic laminates (FRP), delamination may take place between plies and propagate, finally, leading to disaster failure of the structure. Such delamination may not be detected during testing and lead to future disaster damage.

In visual inspections, detecting and predicting failures in laminated composite materials are very complex and it need more than only reasonable techniques of analysis, it needs suitable techniques to classify the failures through predicting their geometry i.e. Size, Shape, and Location. Such failures may produce changes in the physical properties of composite materials; the system reliability could be decreased by decreasing the material’s strength and stiffness.

Thomas Jollivet, et. al.[2] made a numerical investigation on fatigues and fractography in composites. In-service failure case studies are discussed for the ability of design of composite parts and to understand damage micro-mechanisms. The main fatigue mechanisms of damage on both thermoset and thermoplastic composites are discussed. The development of damage is driven by the same process always, first the damage occurrence require low energy consumption in the state of rupture interface (or matrix), while the fiber breakage in last stages require levels of large energy to appear.

Summerscales J. [3] reviewed the defects which may occur during the manufacture of fiber-reinforced composite (FRC) materials, they considered the most criticality defects that have to be detected. The effects of material non-homogeneity and anisotropy are to be examined with non-destructive testing techniques.

Schipperen J.H.A. and de Borst R. [4], focused in their paper on numerical analysis of mixed-mode delamination in T300-5208 graphite-epoxy prepreg laminates. Three different models of materials are discussed. The first two models are based on plasticity, while the last one is based on damage mechanics. Each model is used for the finite element analysis of two different laminate lay-ups. The results are compared both with regard to the material response, the numerical robustness and the computation time.They concluded that the use of plasticity models to determine the behavior of mixed-mode delamination for laminated composites is very sensitive to the selected step size because of the convergence behavior. Models based on damage mechanics of mixed mode delamination are more favorable for the analyses whenever the equilibrium path can be followed easily with relatively large loading steps.

BLOYER D.R., et. al. [5], made a study on the fatigue-crack propagation properties in a series of laminated Nb reinforced Nb3Al inter metallic-matrix composites with variable scale of micro structure. The authors discovered that the resistance to fatigue-crack growth may be improved through increasing metallic layer thickness (in the range 50 mm to 250 mm) oriented in both the crack-divider and the crack-arrester. The fatigue resistance of the crack arrester laminates, indeed, was better than unreinforced Nb3Al and pure Nb fatigue properties for a given layer thickness; both laminate orientations had much better fatigue properties than Nb-particulate reinforced Nb3Al composites.

Addin A. O., et. al. [6], used neural networks to review the failure detection and prediction on laminated composite materials. The considered non-destructive techniques are limited only to natural frequencies, electric conductivity and lamb waves. Their work starts with an introduction to each technique, then summaries and evaluations for some selected related works to the technique are done. Fiber reinforced plastics may range from relatively flexible as glass fibers to extremely stiff materials like carbon fiber and from brittle materials like carbon fibers to extremely as tough as aramid fibers. The performance of such materials is limited by the ability to withstand high stresses.

In this work the effect of the type of reinforcement fibers on the behavior of the crack propagation is studied for samples affected by static loads in uniaxial and biaxial directions associated with open time intervals. To find the best combination of fibers to hold such loads for long duration.

2. Compact Tension Specimen

Compact tension (CT) specimens are notched standard specimens according to (ASTM E647-00) standard test measurement method of fatigue crack growth rates. A fatigue crack is created by cycling the sample to maximum and minimum loads. Indeed, it may be used for quasi static and also static cases. The crack begins from the point of the notch extending through the sample. The fatigue crack is an expression of 'real life' contradictions introduced to a material due to processing techniques. In order to establish fracture toughness values for a material, the CT specimens are widely used in the area of fracture mechanics and corrosion testing. According to the standards, the constraining dimension of a specimen is the material’s thickness. The specimens are used for experiments where there is a shortage of material availability due to their compact design **[7]**. Figure (1) shows the schematic and dimension of standard (CT) specimen.

According to **Bower [8]**, the formula for stress intensity factor (K_I) at the crack tip of the compact tension specimen is:

$$K_I = \frac{P}{B}\sqrt{\frac{\pi}{W}}\left[16.7\left(\frac{a}{W}\right)^{1/2} - 104.7\left(\frac{a}{W}\right)^{\frac{3}{2}} + 369.9\left(\frac{a}{W}\right)^{\frac{5}{2}} - 573.8\left(\frac{a}{W}\right)^{\frac{7}{2}} + 360.5\left(\frac{a}{W}\right)^{9/2}\right]$$

Where:

a : the crack length B : the thickness of the specimen

P : the applied load W : the specimen's width.

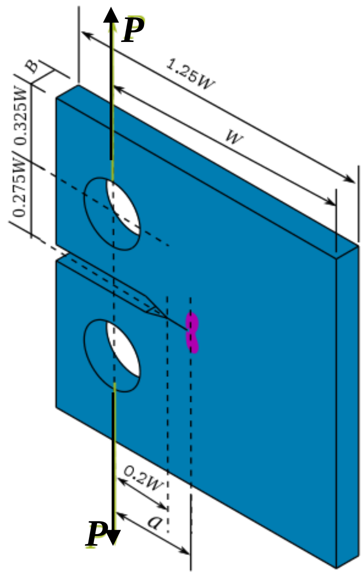

Figure (1): Compact Tension specimen's schematic and dimensions [7].

3. Experiments and Results

Fiber-reinforced polymer composites (GFRP) are widely used in engineering structures components manufacturing in various fields such as marine, high-pressure vessels, support structures, aerospace structures, etc. The increase in composite structures use, has pointed to the need for models that can determine the monotonic and fatigue characteristics of these composites under multi-axial stress fields. Most of the multi-axial fatigue damage models that are based on strain, stress, and energy data; are proposed in an attempt to correlate the data with fatigue life. However, a general theory capable of modeling the fatigue life of a variety of materials subject to different loading conditions is not available as mentioned in **[9].**

Multi-axial loadings may be classified as in-phase (proportional) or out-of-phase (non-proportional). During a proportional loading the principal stress directions remain fixed with time and the principal stress ratio remains constant even though the loading directions rotate **[10].**

Three types of woven fabrics are utilized in this study: E-Glass fiber woven fabric, Kevlar and Hybrid E-Glass-Kevlar in polyester resin. All types are of 45-50 % volume fraction and of four layers with specimen's thickness = 4 mm and the other dimensions are as shown in figure (2). static unidirectional and bidirectional exerted load tests are performed on the specimens. The crack length is measured using Vernier. The measurements are stopped when deviation from normal direction occurred. The rate of crack propagation is assessed on the basis of crack growth time.

In unidirectional test the load is applied on both sides of the specimen in x-direction and the crack length examined during the test within time interval.
Another load in the z-direction is applied to the specimen at the same point of effect to have the biaxial test.

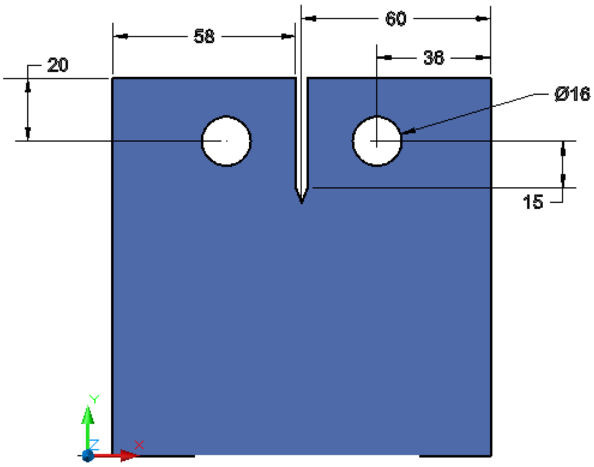

Figure (2): The dimensions of the experimental test specimen

The test results are demonstrated as (crack length/time) curves in figures (3 to 7). Figure (3) includes two curves representing the relationship between the propagated crack length and the time of load application for both unidirectional and bidirectional loads on the fiberglass/ polyester specimens. It can be found that the effect of the biaxial loading reduces the static life time of the specimen for about 26.3%. This percentage is 27.2% in the Kevlar/polyester specimens for the same environmental and loading conditions as shown in figure (4) while, only 12.5% decrease in life time is found in the hybrid specimens as shown in figure (5). The maximum crack length before collapse is nearly the same for uniaxial and biaxial loads in the fiber glass and the Kevlar cases, while in the case of the hybrid sample the maximum crack length decreased about 22%.

From figure (6) declares that the hybrid samples sustained 8% time more than the Kevlar samples which were 13.6% more than the fiber glass samples. Also the maximum crack length of the hybrid samples are greater than the Kevlar and glass samples by 14.4%.

The relation between the propagated crack length and time interval for the three samples at the bi-axial load are shown in figure (7).

It can be noticed that the maximum sustained time in the hybrid samples is 23.8% greater than the Kevlar samples which are in turn greater than the glass samples by 12.5%. but, the maximum crack length for the hybrid samples is less than the Kevlar samples by about 10% and this value for the glass samples is also less than the Kevlar by 2%.

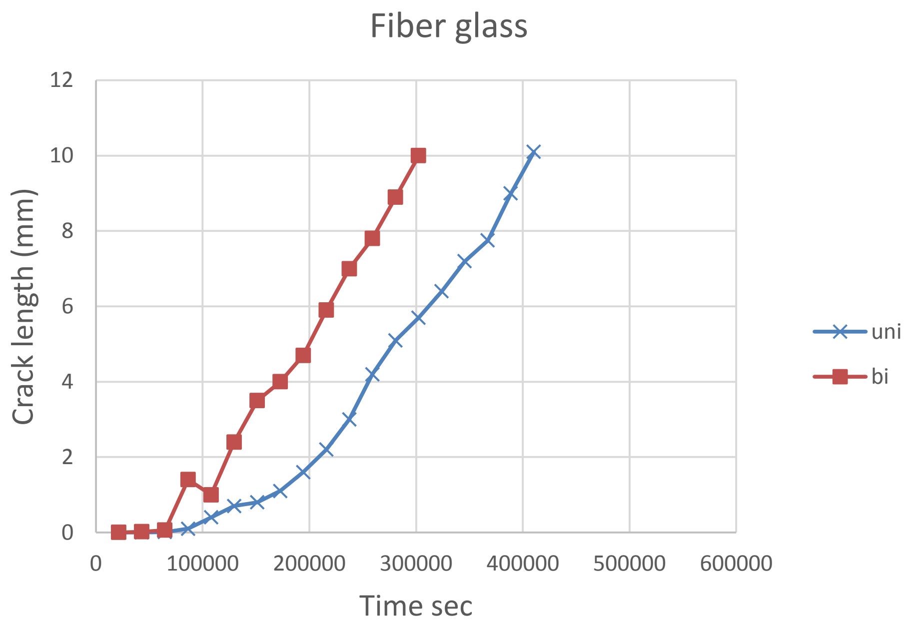

Figure (3): propagated crack length with time line for the fiber glass/polyester specimens for both uniaxial and biaxial loading

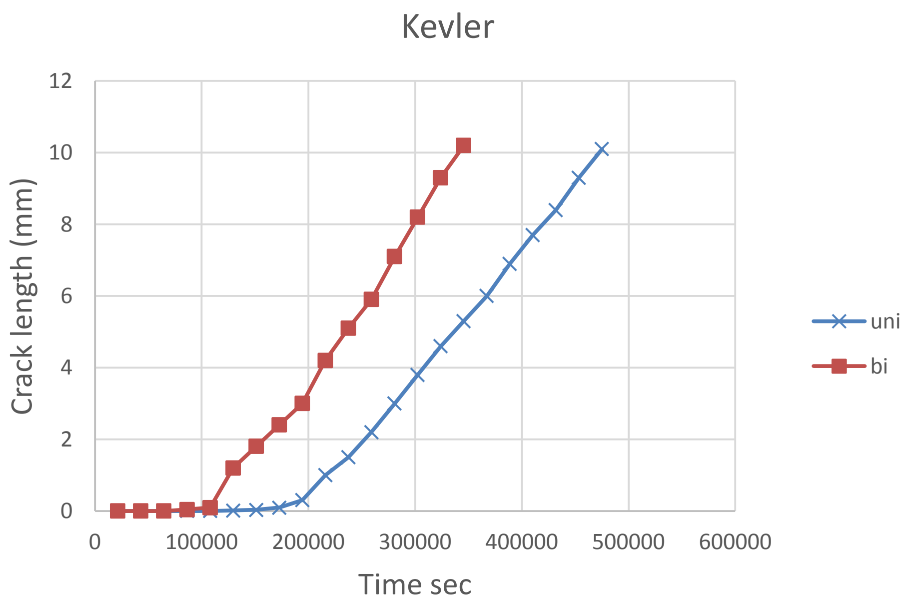

Figure (4): propagated crack length with time line for the Kevlar/polyester specimens for both uniaxial and biaxial loading

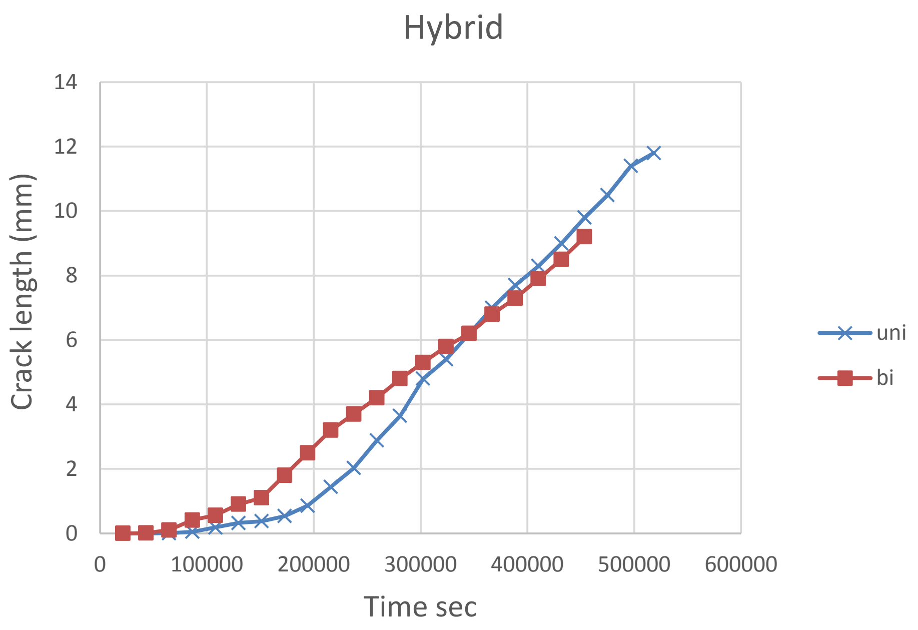

Figure (5): propagated crack length with time line for the Hybrid (fiber glass/Kevlar/polyester) specimens for both uniaxial and biaxial loading

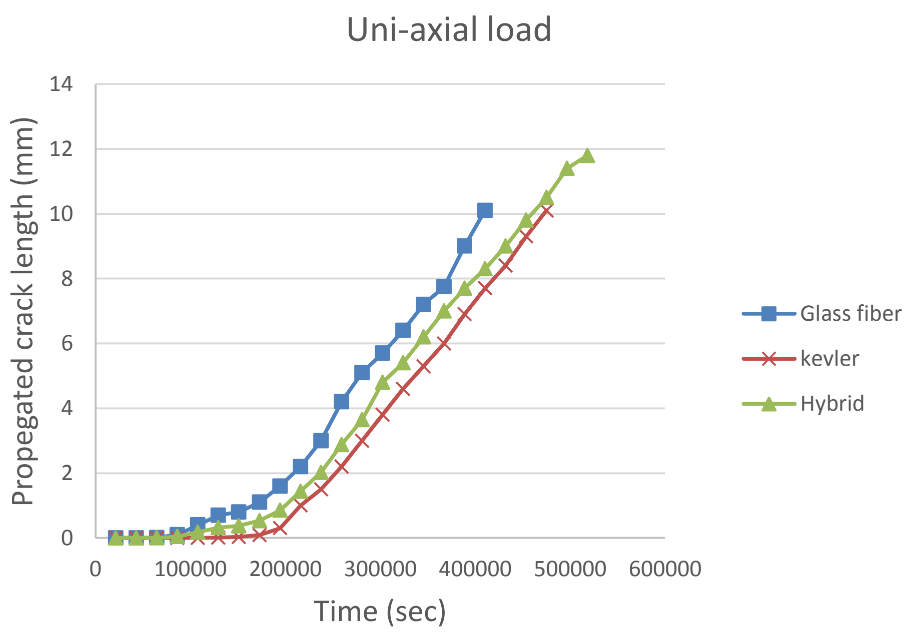

Figure (6): propagated crack length with time line for the three types of specimens for uniaxial loading.

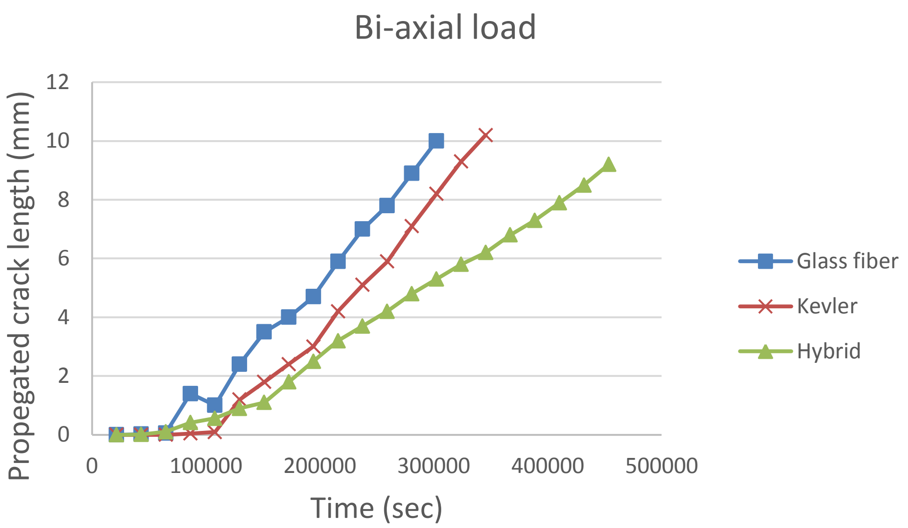

Figure (7): propagated crack length with time line for the three types of specimens for biaxial loading.

4. Conclusions

Through the above paragraphs, it is concluded that although the bi-axial load's effect increases the life time of sample before collapse but, it decrease the critical length of crack edge. Also it is concluded that the hybrid composite fiberglass/Kevlar/polyester can sustain greater crack length for additional period under uniaxial load than those for fiberglass/polyester and Kevlar/polyester.

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