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Fatigue Behavior of unsaturated Polyester/ Polyvinyl Chloride Polymer system Reinforced with E-glass fibre

دراسة سلوك الكلل لخلائط البوليستر\ بولي فينايل كلورايد المدعمة بالالياف الزجاجية

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Abstract

Fatigue behavior of "unsaturated polyester /Polyvinyl Chloride" blends with different weight percentage of PVC(10%,20%,30%),unreinforced and reinforced with one and two laminates of chopped mat E-glass fibre were studied. Bending fatigue loading (Fixed Strain Technique) through out subjecting sinusoidal loading was used to obtain the bending moment m_b and bending stress versus cycles number .The effect weight percentage of PVC, and laminates number of E-glass fibre on the fatigue behavior were investigated by determining the fatigue strength and fatigue life from the plotted S-N curves. The results show that the increasing of PVC-content and E-glass fibres laminate lead to increase the fatigue strength and enhancing fatigue life.

الخلاصة

تمت دراسة سلوك الكلل لخلائط البوليستر\ بولي فينايل كلورايد غير المشبعة متغيرة النسب الوزنية لمادة ال PVC (10%,20%,30%) غير المدعمة والمدعمة بطبقة او طبقتين من الالياف الزجاجية نوع (chopped mat E-glass fiber). استخدمت طريقة فحص الكلل الانحنائي(Bending Fatigue Test) بتسليط جهد جيبي باستخدام تقنية الانفعال الثابت (Fixed Strain Technique) للحصول على عزم انحناء m_b واجهاد نسبة إلى عدد الدورات. تم دراسة تأثير كل من تغير النسب الوزنية للخلائط وتغير عدد طبقات الألياف على سلوك الكلل(مقاومة الكلل, عمر الكلل) من منحنيات (الإجهاد-عدد الدورات). أظهرت النتائج المستخلصة إن زيادة النسب الوزنية لمادة بولي فينايل كلورايد وعدد طبقات الألياف الزجاجية تؤدي إلى زيادة قيم مقاومة الكلل وعمر الكلل.

1-Introduction

A fundamental problem concerning the engineering uses of fiber reinforced plastics (FRP) is the determination of their resistance to combined states of cyclic stress [1].

Although fatigue behavior occurs over time (especially over long periods of time and under the application of many cycles of loading), the phenomenon is not time-dependent; fatigue is a cycle-dependent phenomenon. The cycles of load application may be applied quickly over a long period of time, or discontinuously (with periods of no loading interspersed), with no change in the number of cycles to failure (the fatigue life) [2].

Composite materials exhibit very complex failure mechanisms under static and fatigue loading because of anisotropic characteristics in their strength and stiffness [2].

The fatigue causes extensive damage throughout the specimen volume, leading to failure from general degradation of the material instead of a predominant single crack. A predominant single crack is the most common failure mechanism in static loading of isotropic, brittle materials such as metals[2].

There are four basic failure mechanisms in fibrous composite materials as a result of fatigue: matrix cracking, delamination, fiber breakage and interfacial debonding.The different failure modes combined with the inherent anisotropies, complex stress fields, and overall non-linear behavior of composites severely limit our ability to understand the true nature of fatigue. [3] .

Extensive work has been done to establish failure criteria of composites during fatigue loading. Fatigue failure can be defined either as a loss of adequate stiffness, or as a loss of adequate strength. There are two approaches to determine fatigue life; constant stress cycling until loss of strength, and constant amplitude cycling until loss of stiffness. The approach to utilize depends on the design requirements [4,5,6].

In a constant amplitude deflection loading situation the degradation rate is related to the stress within the composite sample. Initially, a larger load is required to deflect the sample, this corresponds to a higher stress level, as fatiguing continues, less load is required to deflect the sample, this corresponds to the reduction in the stiffness of the sample. In constant amplitude fatigue, the stiffness reduction is dramatic at first as substantial matrix degradation occurs, and then quickly reduced off until only small reductions occur [7].

Fatigue tests depend on the type of stress action that is applied to the specimen. Studies have been made on the cyclic fatigue under normal tension–tension, tension–compressive, impact, torsion and bending of glass fibre reinforced polymer composites.

E. Kristoffer Gamstedt [7] used tension-tension fatigue to study fatigue damage mechanisms in polymer matrix composites. The underlying fatigue damage mechanisms were investigated for unidirectional carbon fiber and glass fiber reinforced epoxy. Macroscopically, the weak interface composites showed shorter fatigue lives and more rapid fatigue degradation. This suggests that higher interfacial strengths lead to improved fatigue performance.

R. ROY et al [8] used impact fatigue for over 10^4 impact cycles to study the fatigue behavior ,they used two types of unidirectional carbon fibre, one of high strength (DHMS) and another of medium strength (VLMS) to reinforce vinylester resin. The study was conducted by using a pendulum type repeated impact apparatus specially designed, and constructed for the purpose. A well-defined impact fatigue behavior (S–N type curve) has been demonstrated. It showed a plateau region of 10–10^2 cycles immediately below the single cycle impact strength, followed by progressive endurance with decreasing impact loads, culminating in an endurance limit at about 71% and 85% of the single impact strength for DHMS-48 and VLMS-48, respectively .

Daniel D.Samborsky et al. [9]studied the delamination resistance to axial fatigue loading by using three different types of fibres ,Two were unidirectional carbon (NCT307-D1-34-600-G300) and (NCT307- D1-E300), and one was E-glass 0/90 woven fabric (NB307-D1-7781-497A) orientated at 45° for ±45 plies, reinforcing epoxy resin. The experimental results of this study indicate that ply drops in laminates can lead to delamination at relatively low applied strains under fatigue loading.

A study of fatigue behavior by A.A. Hasan [10] under bending fatigue loading for Epoxy /Polyurethane blends, unreinforced and reinforced with different laminate number of E-glass fibers type Woven Roving (WR) with orientation 0^0,90^0. He showed that the reinforcing lead to increase the fatigue strength and enhancement of fatigue life. And fatigue life decreased with the increase of polyurethane ratio in these blends.

In the present work bending fatigue loading (Fixed Displacement Technique) was used to study the effects of PVC wt%, and reinforcing with CM E-glass fibre on fatigue behavior (fatigue strength and fatigue life) of UPE/PVC blends.

2-Materials and Preparation

The polymers used were unsaturated polyester resin (containing styrene as a cross–linking agent) type H-265, with hardener MEKP and accelerator cobalt naphthenate, supplied by IPI Jordan, and PVC powder , supplied by industrial chemical and resin CO. LTD , Chopped strand mat Glass fibers type E- glass was used as a reinforcement, supplied by company (Molding, LTD. UK) .

Two groups of test samples were prepared as sheets by hand lay-up technique. The first group of Polyester/PVC blends were prepared with different weight percentages of PVC content (10%, 20 % and 30 %), the second group were prepared by using the same blend ratios reinforced by one or two laminates of chopped strand mat E-glass fibers, the sheets of the two groups were cut to a certain dimensions samples(30m.x90m.) according to the fatigue instrument specification as shown in Fig.1 by using a circular saw , the details of the prepaired samples group are given in table1.

Fig. 1. Geometry and dimensions in mm. of fatigue test specimens.

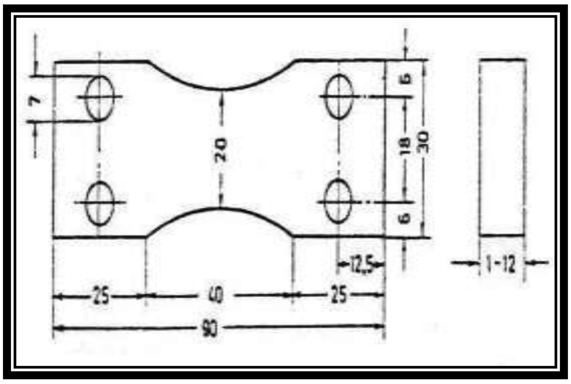

Table 1. Details of test samples Groups

	UPE%+PVC%	No. of E-glass fibres laminates
First group	90%+10%	0
	80%+20%	0
	70%+30%	0
Second group	90%%+10%	1
	90%%+10%	2
	80%+20%	1
	80%+20%	2
	70%+30%	1
	70%+30%	2

3-Fatigue test

The fatigue test was carried out by using the fatigue machine (type PWON made by CARL SCHENCK AG.), under bending fatigue loading (displacement controlled) to obtain the bending moment m_b values that can be read from the characteristic curve of deviation versus bending moment plotted by the manufacturer. The bending stress values were determined from bending moment values by using equation (1) according to the instrument manual[10].

$$\sigma = \frac{m_b}{W} \quad \ldots\ldots\ldots\ldots(1)$$

where

$$W = \frac{b^2 h}{6} \quad \ldots\ldots\ldots(2)$$

m_b = bending moment(Nm).
b = the width of specimen west (mm).
h = thickness of specimen (mm).

All the prepared specimens were subjected to a fully reversed bending fatigue test, of constant displacement that cause deflection equal to (D=8 mm) to obtain their number of cycles to failure (N_f) , The type of loading was sinusoidal wave. The resulted fatigue stress alternates between positive value σ_{max} and negative value σ_{min} of equal magnitudes such that the stress ratio($R=\sigma_{min}/\sigma_{max}=-1$),the fatigue loading frequency was set at 5 Hz , which is believed to give a negligible temperature rise during test[1] .
σ-N curves were plotted between the bending stress and the cycles number, from which the fatigue strength for a given number of cycles and fatigue life were determined for the tested specimens .

4-Results and discussion

The plotted curves of figures (2-4) show a reduction in the measured bending stress with increasing the cycles number until reaching failure stage for all samples. This can be explained as, subjecting the samples to bending stress cause breakage of bonds of the main polymeric chains. Note worthy the fatigue failure of the specimens is always accompanied by deceasing in the flexural rigidity. In constant amplitude deflection loading situation, the degradation rate is related to the stress within the composite sample. Initially, a larger load is required to deflect the sample. This corresponds to higher stress level, As fatigue test was continue, less load is required to deflect the sample due to reduction in stiffness [6].

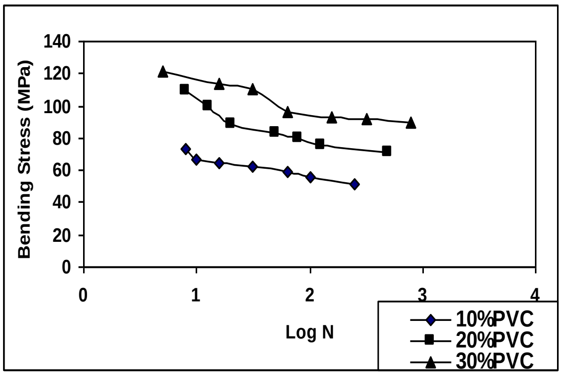

Fig.2. Variation of bending stress versus cycles number for UPE/PVC blends with different PVC wt%

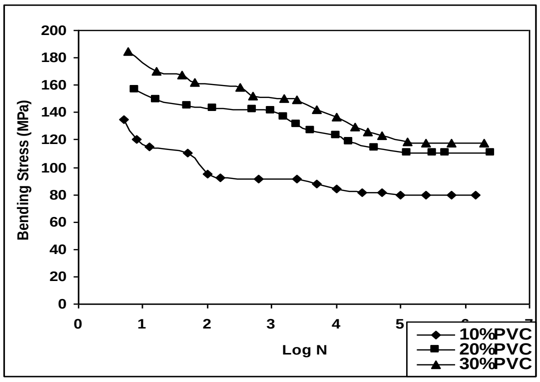

Fig.3. Variation of bending stress versus cycles number for UPE/PVC blends reinforced with one layer of fibers

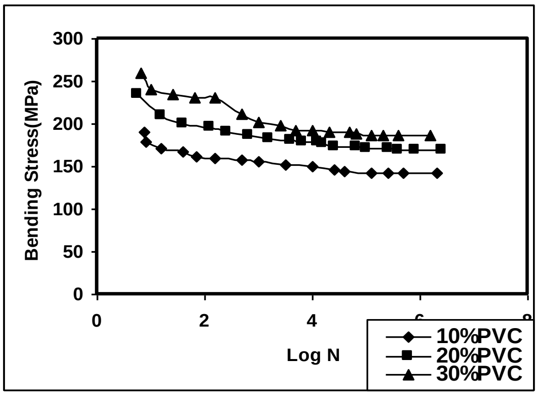

Fig. 4. Variation of bending stress versus cycles number for UPE/PVC blends reinforced with two layers of fibers

4-1-The Effect of PVC wt% of UPE/PVC Blends:

Fig.2. shows the fatigue behavior of blends with different PVC wt% which were subjected to fatigue loading eventually constitutes a mechanical deterioration and progressive fracture that leads to complete failure. In general fatigue of blends involves two stages, first is the initiation of a crack and second is the subsequent crack growth to fracture at the stressed region as shown in Fig.5. Fracture ultimately occurs when the crack is large enough that the uncracked section is unable to support the applied load and the specimen fractured.

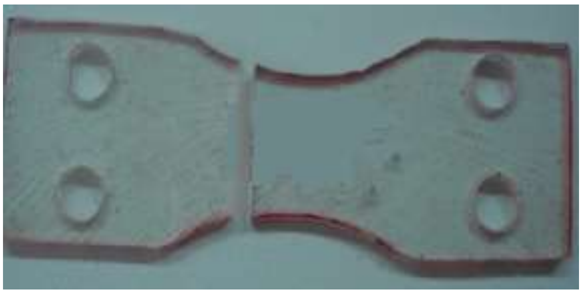

Fig.5. Fracture at the stressed region of unreinforced specimen

Fig.2. also shows that the ultimate failure occurred faster in blend of less PVC content (fractured at less cycles number). Fatigue strength σ_f for 10^2 cycles and fatigue life N_f for the tested blends were determined and listed in Table 2., no fatigue limit can be detected for the unreinforced blends since the ultimate failure the specimens occurred as fracture at the stressed area .It is clear that increasing the proportion of PVC content has improved the fatigue behavior of the tested specimens by increasing the fatigue strength and fatigue life .

Table 2. Fatigue strength σ_f for 10^2 Cycles and Fatigue life N_f for UPE/PVC blends

PVC %	σ_f (MPa)	N_f Cycles number
10%	40	$2.2x10^2$
20%	56	$4.1x10^2$
30%	73	$5.7x10^2$

4-2-The Effect of Reinforcing by E-glass Fibre:

The plotted curves of Fig.3 and Fig.4 for the tested specimens reinforced with one and two laminates of chopped mat (CM) E-glass fibers, declare the bending stress values higher than those of unreinforced blends, The explanation of this behavior is that the addition of fiber glass increases the stiffness of polymeric martial which in turn reflected as an increase of bending stress value since high stiff martial displays high bending stress while elastic one displays low bending stress[11]. Fatigue strength for 10^5 cycles, fatigue life and fatigue limits were determined from the plotted curves and listed in Table 3 and Table 4 that reveal reinforcing by E-glass fibre lead to raise the fatigue strength and fatigue life.

Table3. Fatigue strength σ_f for 10^5 Cycles,Fatigue life N_f and fatigue limit for UPE/PVC blends reinforced with one laminate of CM E-glass fibre

PVC %	σ_f (MPa)	N_f Cycles number	Fatigue Limit (MPa)
10%	84	$0.9x10^6$	80
20%	123	$4.2x10^6$	110
30%	142	$5.1x10^6$	118

Table 4. Fatigue strength σ_f for 10^5 Cycles, Fatigue life N_f and fatigue limit for UPE/PVC blends reinforced with two laminates of E- glass fibre

PVC %	σ_f (MPa)	N_f Cycles number	Fatigue Limit (MPa)
10%	150	$2.1 X10^6$	141
20%	178	$5.5 X10^6$	172
30%	192	$7.3 X10^6$	184

Also Table 3 and Table 4 show the fatigue strength higher in specimens reinforced with two laminates of E- glass fibre This can be attributed to the presence of more fibres and interface area that transfer stresses from matrix to fibres. all the reinforced specimens did not suffer of fracture during the course of the test because the reinforcing fibres has high stiffness that gives more rigidity to the samples.

5-Conclusions

It is concluded that PVC content is responsible for improving the fatigue behavior of unreinforced blends, such that increasing the weight percentage of PVC raises the fatigue strength and elongates the fatigue life. It is also concluded that reinforcing the unsaturated Polyester/PVC blends with E-glass fibre has strong influence on enhancing fatigue strength and fatigue life for the tested specimens**.** Finally specimens reinforced with two laminates have higher fatigue strength and longer fatigue life than those reinforced with one laminate

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