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EFFECT OF STRAIN RATE ON TENSILE FRACTURE BEHAVIOUR OF VISCOELASTIC MATRIX (POLYESTER) AND FIBER REINFORCED COMPOSITES

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Abstract:

Tensile testing of matrix and four different fabric polyamide composites was performed at various loading rates ranging from (8.16* 10-5 to 11.66 * 10-5 m/sec) using a servohydraulic testing apparatus. Four kinds of reinforcements woven glass fiber (WGF), random glass fiber (RGF), kevler fiber (KF) and carbon fiber (CF), and one kind of viscoelastic matrix, polyester (P). The results showed that the linear strain (≤ 0.5) the three parameter model gives a good agreement with experimental results. The elastic modules of the viscoelastic matrix and composites tend to increase with increase of both strain rate and time. The experimental results were comparison with numerical results for simple study case has shown some agreement, which indicate the effectiveness of the ansys program used.

Key words: viscoelastic, tensile behavior, polyamide composite, strain rate dependence, high speed testing, fiber.

Introduction:

In practical engineering design, deflections and stresses are very important criteria in reliability and serviceability evaluations of structures. Viscoelasticity is an important concept for determining long – time behaviour (service-life time) of structures. Viscoelasticity permits us to describe the behaviour of materials exhibiting strain rate effects under applied loads. These effects are illustrated by creep phenomena under certain loads or by stress relaxation under a constant deformation. For most composites, the viscoelastic behaviour is primarily due to the matrix. Composite materials are reinforced with fibers in part to resist creep deformation. The magnitude of the creep deformation induced in a composite structure under a certain loading is influenced by a variety of factors, such as material architecture, temperature, humidity, loading frequency, and stress level [1]. Tensile testing of continuous fiber reinforced polymer composites has been performed to characterize the tensile mechanical behaviour of the composites. Mechanical properties such as elastic modulus were obtained in these studies by using tensile testing systems [2]. The assumptions used are that the matrix is linear viscoelastic and the fibers are elastic. The viscoelastic analysis techniques may

broadly be classified into three approaches, viz. (i) quasi-elastic solutions, (ii) integral transform techniques, and (iii) direct methods. Quasi-elastic solution uses elastic properties equivalent to the corresponding viscoelastic properties at the desired time and temperature. This approach essentially ignores the entire past history of loading and environment and therefore yields gross approximation to the true response. Integral transform technique [3] is based on the corresponding principle, in which using the elastic solution, the corresponding viscoelastic solution is obtained using Laplace transform technique. This approach is exact for which closed form solutions are possible and approximate Laplace transform inversion has to be employed for the problems with the numerical elastic solution [4]. Further, the transform technique is not directly applicable for the problems of non-homogeneous transient temperature distributions. To circumvent these problems, conditions of constant temperature over time increments are imposed and the correspondence principle is applied on an incremental basis [5]. The direct formulations are based on the finite element theory using either the differential form [6, 7] or the integral form [8, 9] of stress-strain relationships.

In this work studying the behaviour of one matrix are used and four different types of composite beams. Package program (ANSYS 5.4) are used in this work to compression between experimental results with numerical results for these four types of composite beam at greatest load used and studying new cases illustrated the viscoelastic composite behaviour.

It is well known that the straightforward application of the displacement method to nearly incompressible structures yields erratic displacements and severely oscillating stresses about the exact solution and across the elements. This aspect has been studied for elastic materials and is well documented in literature [10]. The remedies suggested in literature to overcome the difficulties are the use of: (i) refined meshes, (ii) reduced Poisson's ratio, (iii) alternate formulations. Such as the stress hybrid approach and the formulation based on Hermann's(Semi-Reissner's) variational principle, and (iv) reduced integration for the troublesome portion of the strain energy. The proposition of mesh refinement [11] needs number of elements and yields doubtful results and therefore is not advisable. The results obtained using the reduced Poisson's ratio has to be extrapolated so as to obtain the results corresponding to the required Poisson's ratio [12].

Viscoelastic Model:

The mechanical model is equivalent to describe the viscoelastic behavior and construct of elastic spring, this will obey Hooke's laws, and viscous dashpots, which obey Newton's law of viscosity [13].

The simplest mechanical model is a combination of one spring with one dashpot linked either in parallel (Voiget or Kelvin model) or in series (Maxwell model) [14]. Each spring element is assigned a stiffness (E), which represents modulus of elasticity, and each dashpot is assigned a frictional resistant (force-velocity of displacement), λ which represent the viscosity [15].

The two models couldn't satisfy the viscoelastic properties (creep and relaxation) completely if they are

used alone, the combination between two models (Maxwell- Kelvin model) gives good results in both creep and relaxation [16].

Maxwell model:

A spring and dashpot in series, as shown in Fig .1, form this model. For simple tension as σo is applied at t = 0, an immediate elastic strain εe of the spring occurs. Then a viscous strain εv of daspot is added. The total strain is equal to the sum of the strain in each component. While the stress acts on them is the same. The total strain can be written as:

$$\varepsilon = \varepsilon^e + \varepsilon^v \qquad \text{.........(1)}$$

Then the strain rate is:

$$\frac{d\varepsilon}{dt} = \frac{d\varepsilon^e}{dt} + \frac{d\varepsilon^v}{dt} \qquad \text{.........(2)}$$

Thus, the governing equation of Maxwell model is:

$$\frac{d\varepsilon}{dt} = \frac{1}{E} \bullet \frac{d\sigma}{dt} + \frac{\sigma}{\lambda} \qquad \text{.........(3)}$$

It is of interest to examine the response of such a material to various stress and strain histories. In the case of the application of constant stress, equation (3) is reduced to:

$$\frac{d\varepsilon}{dt} = \frac{\sigma}{\lambda} \qquad \text{.........(4)}$$

then by integration,

$$\varepsilon = \frac{\sigma t}{\lambda} + \frac{\sigma_o}{E} \qquad \text{.........(5)}$$

Equation (5) explains that only viscous flow is observed with time. After the time t1, the stress σ is removed; an immediate recovery of elastic component of strain occurs leaving irreversible strain of viscous element as shown in Fig.2. For the case of constant strain as shown in Fig.2, equation (3) will be:

$$\frac{d\sigma}{\sigma} = \frac{-E}{\lambda} dt \qquad \text{.........(6)}$$

by integration,

$$\sigma = \sigma_o \exp\left(\frac{-t}{t'}\right) \qquad \text{.........(7)}$$

Where (t' = λ / E) is the 'relaxation time'.Fig. 2 shows the creep and recovery, stress relaxation for Maxwell models [14].

Voiget or Kelvin Model:

This model consists of spring and dashpot in parallel as shown in Fig 3. As σo applied, a dashpot prevents an instantaneous extension of the elastic spring. With time, the viscous behavior causes an increase of the strain. The total strain, elastic strain, and the viscous strain are equal, and each component supports a portion of σo. therefore:

$$\sigma_o = \sigma = \sigma^e + \sigma^v \qquad \text{.........(8)}$$

$$\sigma = E\varepsilon + \lambda \frac{d\varepsilon}{dt} \qquad \text{.......(9)}$$

Beginning with the creep, where the model supports to constant stress, the solution of governing equation (9) is:

$$\varepsilon = \frac{\sigma_o}{E}\left[1 - \exp\left(\frac{-t}{t''}\right)\right] \qquad \text{....(10)}$$

Where t" = λ / E is the retardation time.

Comparison equation (10) and equation (5) indicate that, the predicted creep behavior of the Kelvin model is more realistic, since the strain approaches to σo / E as time approaches infinity [17]. The response of Kelvin model to constant load is most readily understood by considering the recovery response, where σ = 0, then

$$E\varepsilon + \lambda \frac{d\varepsilon}{dt} = 0 \qquad \text{.........(11)}$$

By integration:

$$\varepsilon = \varepsilon_o \exp\left(\frac{-t}{t''}\right) \qquad \text{.........(12)}$$

Fig .4 shows the creep and recovery behavior of Kelvin model. Consider now Kelvin model subjected to constant strain as shown in Fig .4, then equation (9) will be reduced to:

$$\sigma = E\varepsilon \qquad \text{.........(13)}$$

Equation (13) implying that the material behaves as an elastic solid which is an dequate for general viscoelastic behavior [17]. It is shown that Maxwell model gives a reasonable prediction of relaxation but it has unlimited deformation, whereas, Kelvin models provide a better prediction for creep and recovery but it provides for a maximum displacement limited by the elastic deformation of the spring [18].We used in this study the another simple and more general than Maxwell or Kelvin model is the standard linear solid, which is formed by the combination of Maxwell or Kelvin model as shown in Fig .5. It exhibits an instantaneous glassy response as well as delayed elasticity and recovery [19]. Fig.6 shows the creep, recovery and stress relaxation of the standard linear solid, which are more realistic than Maxwell or Kelvin model.

The shear relaxation modulus and creep compliance of shear stress is shown in Fig .5a.

$$G(t) = E_o + E_1 e^{-t/t_1} \quad , \quad \ldots\ldots\ldots\ldots(14)$$

Where:

$$t_1 = \lambda_1 / E_1 \,,$$

$$J(t) = \frac{1}{E_o} - \frac{E_1}{E_o(E_o + E_1)} e^{-t/t_2} \,, \quad (15)$$

Where:

$$t_2 = E_1 E_2 / \lambda_1 \,,$$

While the shear relaxation modulus and creep compliance of Fig .5b is shown below,

$$G(t) = \frac{E_1 E_o}{E_1 + E_o} + \frac{E_o^2}{E_1 + E_o} e^{-t/t_1} \,, \quad (16)$$

Where:

$$t_1 = (E_o + E_1) / \lambda_1 \,,$$

$$J(t) = \frac{1}{E_o} + \frac{1}{E_1}\left(1 - e^{-t/t_2}\right) \,, \quad (17)$$

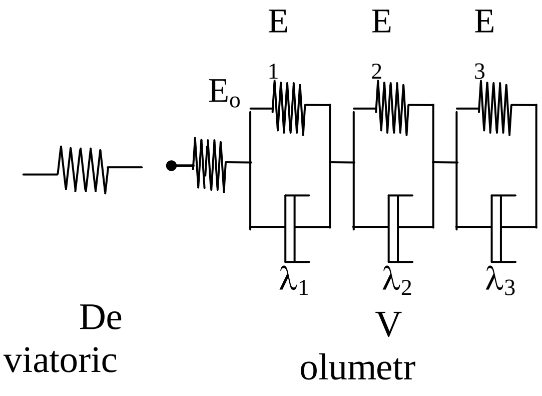
Where:

$$t_2 = \lambda_1 / E_1 \,,$$

The behavior of these models under on entirely different set of condition provides a reasonable predication of real materials [18].

Shear Elastic Modulus:

It will be necessary to describe the definition and measurement of the parameter is used to quantify viscoelastic effects. Experimental work gives the shear elastic modulus by using the tensile test for (P). By using the curve fitting program can be obtained to the coefficient of the shear relaxation. This program used the last square method to solve the apolonomal equation. Fig .7 shown that the comparison between the experimental results with the results of the curve fitting program for the shear elastic modulus with the time. All constant parameters of the viscoelastic material are as shown in the following Table.1. The rheological model is the Generalized Kelvin and Maxwell model in deviatoric component and elastic in volumetric component as shown below:



Experimental Procedure:

Material and Specimen:

Four different polyamide composites were studied in this work. Plain woven or random fiber cloth made of E-glass fiber (GF) and Carbon fiber (CF) was used as the reinforcement in these composites. The matrix was polyester (P). The three composites are denoted here after by WGF/P, RGF/P, and WGF+CF/P. the fiber volume fractions were 35% for WGF/P at 8 layers, 26% for RGF/P at 9 layers, 42% for WGF at 10 layer and 6% for CF at 4 layers for WGF+CF/P. Tensile specimens were cut from the laminates and the direction of the warp threads corresponded with the tensile loading direction. Specimen geometry has shown in Fig.8.

Results and Discussion:

Tensile Testing:

Stress-strain relations of (P) at three different loading rates are shown in Fig.9. For four different polyamide composites the stress – strain relations obtained at the (11.6* 10-5 m/sec) are shown in Figs.10, 11, 12. It has been postulated that the nonlinearly in woven fabric composites is caused by micro mechanical deformation such as shear deformation of the longitudinal threads, extensional deformation of the matrix regions and transverse cracking of the transverse thread [20]. It is clearly seen from Figs.10, 11, 12 that the nonlinear stress-strain behavior was much larger in the woven glass fiber composites than that in the random glass fiber composites. Dependence of the initial tensile modulus on strain rate is shown in Figs.13, 14, 15. The tensile module of all P, WGF/P, and RGF/P tended to slightly increase as strain rate increased, while this modulus appeared decrease as time increased as shown in the Figs.16, 17, 18. Figs.14, 15, 16 and 17 shows that the tensile modulus of the EGF composites was larger than that of the WGF composites. All these occurs as many reasons some of these reasons, firstly because the failure strain of the EGF composites was larger than of the of the RGF composites as expected because EGF fiber generally shows larger elongation than RGF. Another reasons because the absorbed energy for the EGF fiber composites was higher than of the of the RGF composites at all strain rates tested.

Numerical Results:

After making a preview for the experimental work, Figs. 19 to 25 show the comparison between the experimental results for each model on the greatest load used for viscoelastic composite beam with the software solution for the viscoelastic beam for the same geometry and characteristics. The general behavior of polyester seems to be stable, though it is increasing slowly with the course of time. This can be seen clearly from the experimental results.Figs.19, 21, 23, 24 and 25 show some how approximate results. The results shown in Fig .24 on the model shows a good agreement when compared with the other figures above because the applied load on this model is more suitable with the numbers of layers used. Fig.21 shows that behavior of viscoelastic beam increases with the time and exceeds viscoelastic composite beam limits because the numbers of the layers with the applied load are harmonic. Therefore, the effect of the load on this model appears. Fig.22 shows that viscoelastic composite beam exceedsviscoelastic beam limits. This is due to the low load used in addition to the existence of residual stresses in

the viscoelastic composite beam during the manufacturing.

Conclusions:

1. Tensile fracture properties of this type of matrix and four different polyamide composites were studied at loading from (8.16*10-5 to 11. 66*10-5 m/sec) using tensile testing apparatus.

2. Carbon fiber composite and E-glass fiber composite with polyester matrix showed better tensile performance at all testing rates than woven E-glass fiber composite with polyester and random E-glass fiber composite with polyester. 3. Polyester matrix has shown very good fracture resistance. The tensile test shows that clearly and the resistance against the effective load is very good.

4. The tensile mechanical properties of this composite dramatically increased as strain rate increased. On the other hand, the elastic modulus of both matrixes only and composite decreased as strain rate increased and then slightly decreased at high strain rates. As a result, the elastic modulus in general increased as the strain rate increased.

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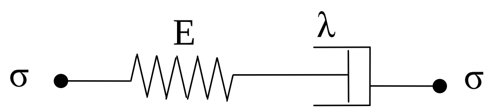

Fig. 1 Maxwell Model.

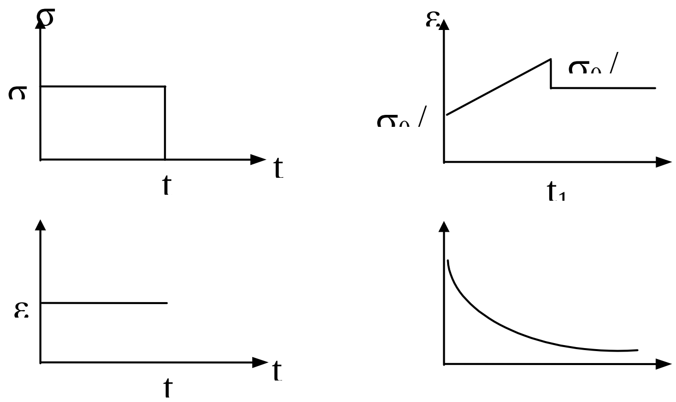

Fig. 2 Creep and Recovery of Maxwell

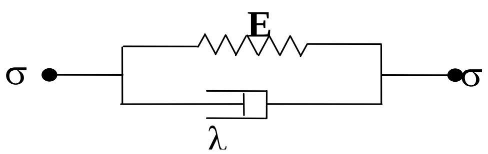

Fig. 3 Kelvin Model.

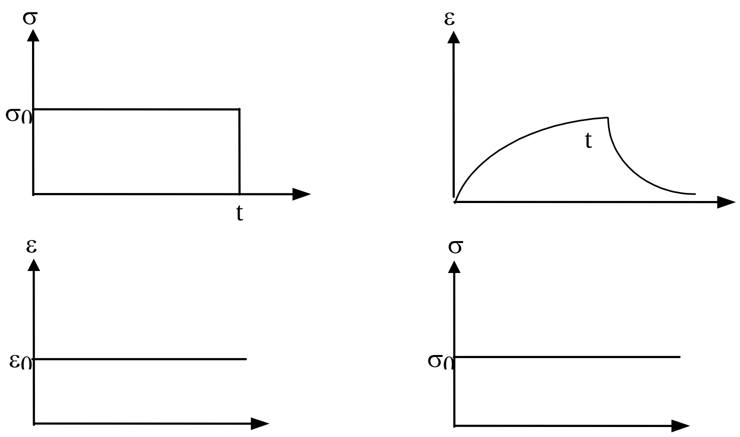

Fig. 4 Creep, Recovery & Relaxation Behavior of Kelvin Models

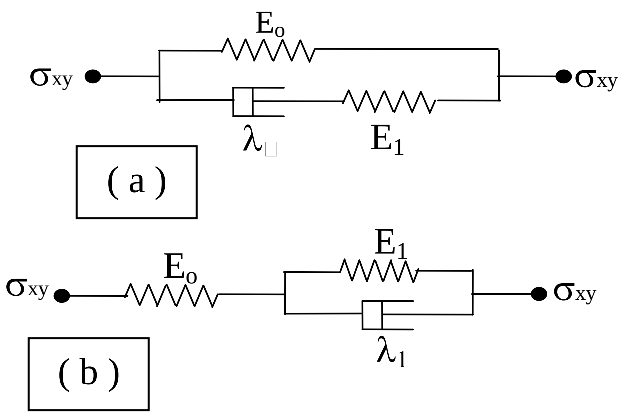

Fig.5 Standard Linear Solid Model.

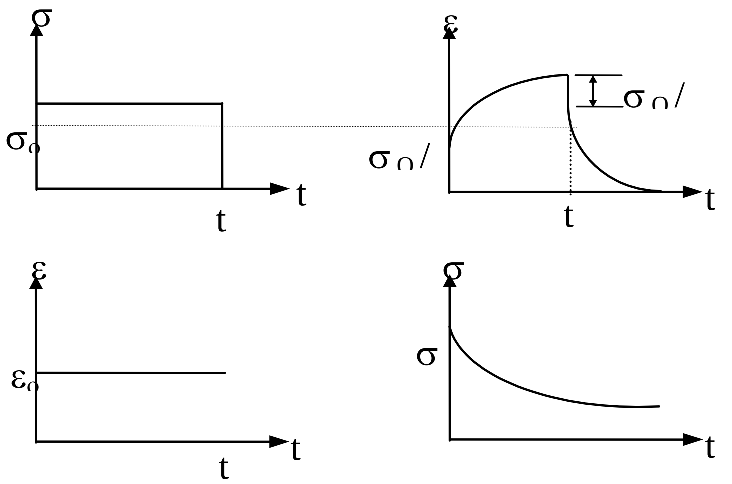

Fig.6 Creep, Recovery & Relaxation Behavior of Standard Linear Solid Model.

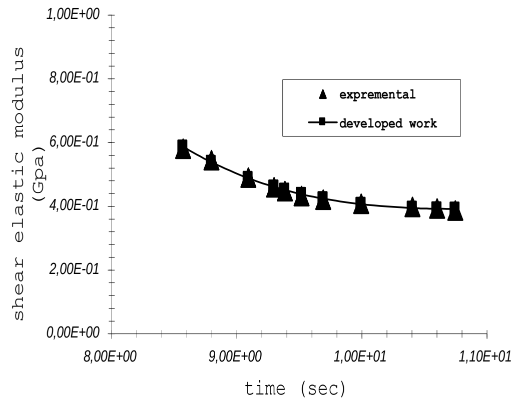

Fig.7 Shear Elastic Modulus of Polyester.

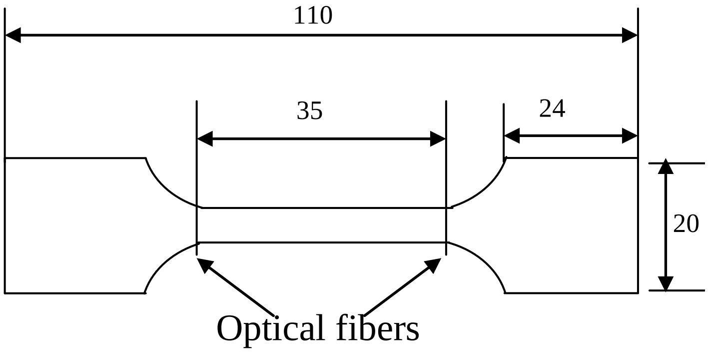

Fig.8 Tensile Specimen Geometry.

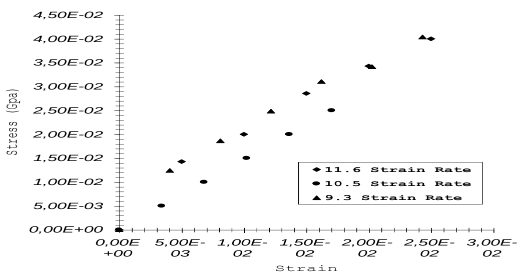

Fig.9 Tension of Polyester.

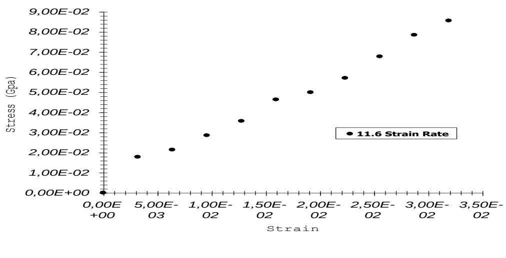

Fig.10 Tension of RGF / P.

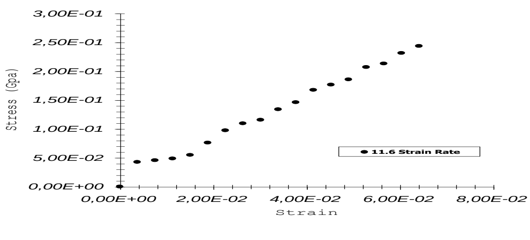

Fig.11 Tension of WGF + CF / P.

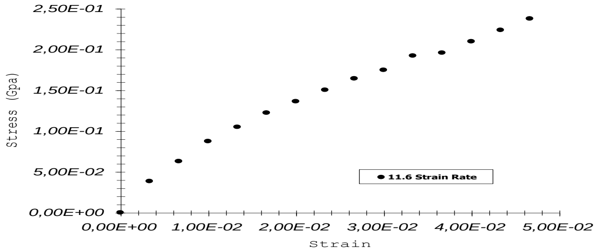

Fig.12 Tension of WGF / P.

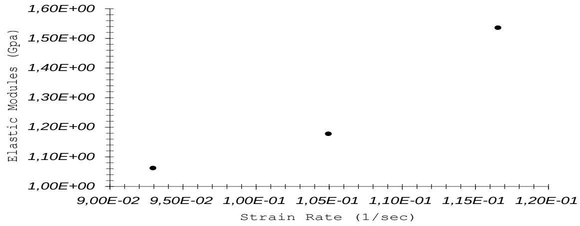

Fig.13 Elastic Modules vs. Strain Rate of Polyester.

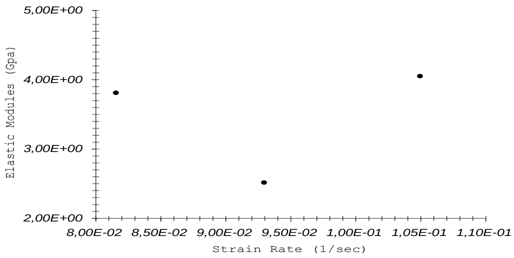

Fig.14 Elastic Modules vs. Strain Rate of RGF / P.

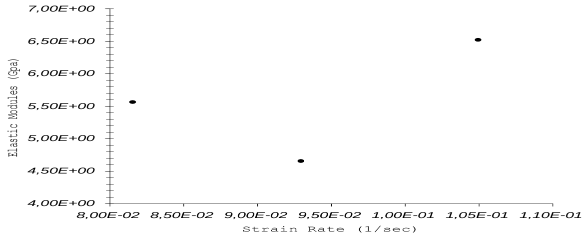

Fig.15 Elastic Modules vs. Strain Rate of WGF/ P.

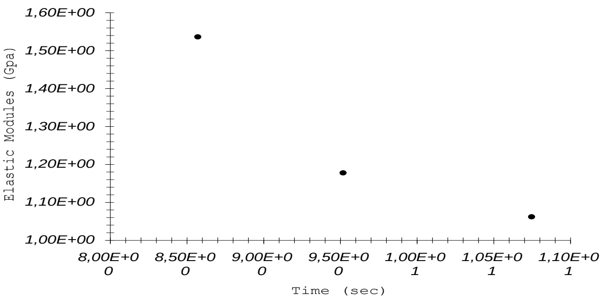

Fig.16 Elastic Modules vs. Time of Polyester.

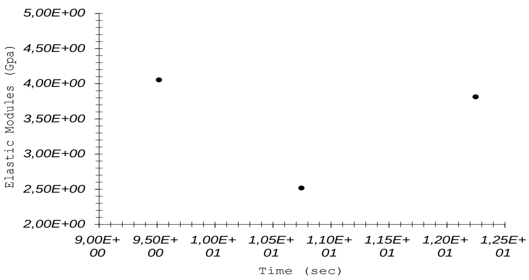

Fig.17 Elastic Modules vs. TIME of RGF / P.

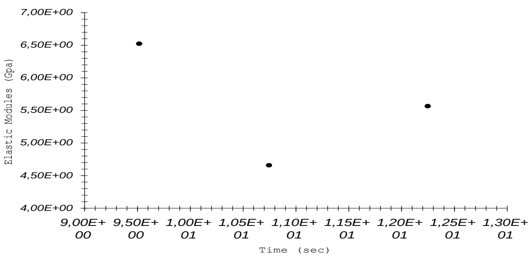

Fig.18 Elastic Modules vs. Time of WGF / P.

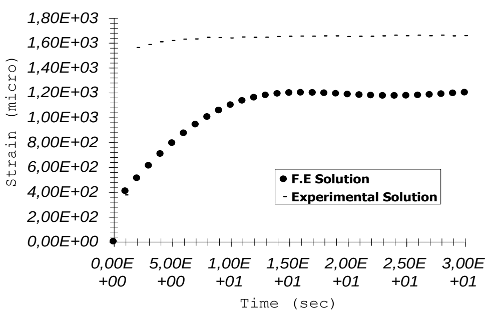

Fig .19 Comparison Between Viscoelastic Composite (P+RGF 8 layer) with Viscelastic (P) at (9 N).

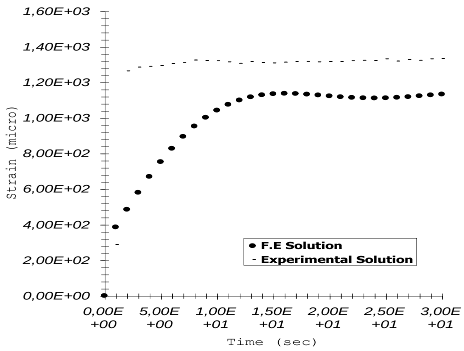

Fig .20 Comparison Between Viscoelastic Composite (P+RGF 9 layer) with Viscelastic (P) at (30 N).

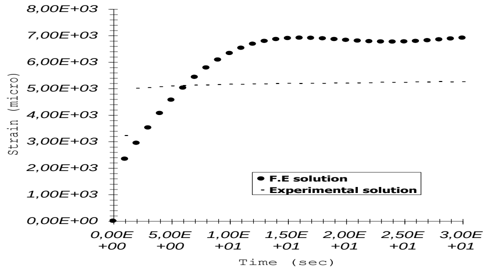

Fig .21 Comparison Between Viscoelastic Composite (P+WGF 8 layer) with Viscelastic (P) at (40 N).

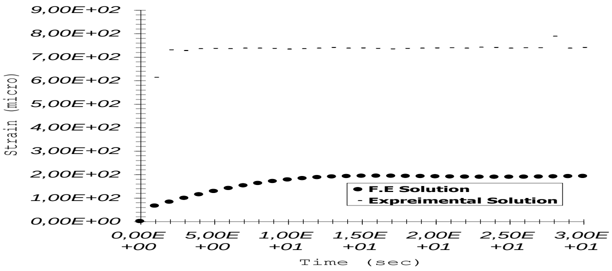

Fig .22 Comparison Between Viscoelastic Composite (P+WGF 10 layer +CF 4 layer) with Viscelastic (P) at (7 N).

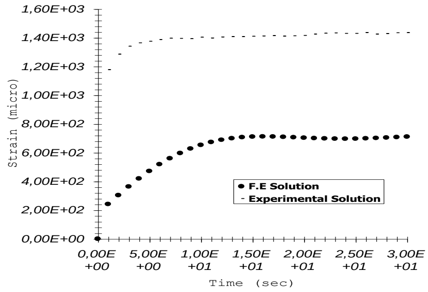

Fig .23 Comparison Between Viscoelastic Composite (P+KF 2 layer +CF 1 layer) with Viscelastic (P) at (11 N).

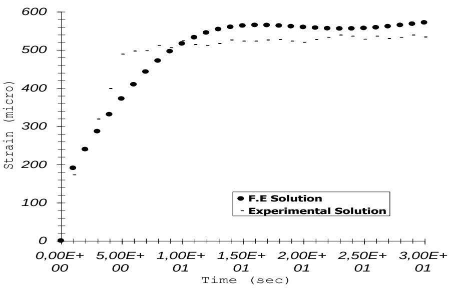

Fig .24 Comparison Between Viscoelastic Composite (P+KF 5 layer +CF 6 layer) with Viscelastic (P) at (70 N).

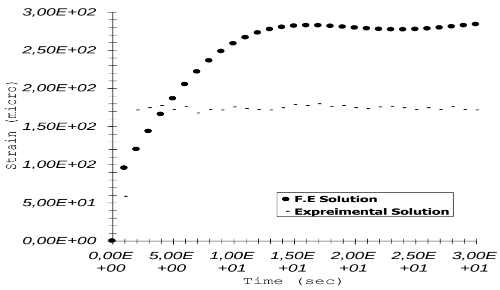

Fig .25 Comparison Between Viscoelastic Composite (P+KF 8 layer +CF 7 layer) with Viscelastic (P) at (70 N).

Matrix type	Parameters							
	E0	E1	E2	E3	λ1	λ2	λ3	K
Polyester	-41.22	4.005 E04	-5.869 E04	1.871 E04	0.106	0.103	0.096	1.478 E09

تأثير معدل الانفعال على معامل الكسر للمواد المركبة من مواد مرنة لزجة (بوليستر) وألياف رابطة

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المستخلص

أجريت دراسة عملية تم فيها استخدام جهاز اختبار الشد الهيدروليكي أولا للمادة الرابطة والمتمثلة بالمادة المرنة اللزجة (بوليستر) وثانيا لأربع أنواع مختلفة من المواد المركبة والتي استخدم فيها نفس المادة الرابطة مع اختلاف الألياف المستخدمة وهي الألياف الحصيرية الزجاجية و الألياف العشوائية الزجاجية وألياف الكفلر وألياف الكربون وتم الاختبار عند نسب أحمال مختلفة تتراوح من(٨,١٦ * ١٠ -٥ م/ثانية) إلى(١١,٦٦ * ١٠ -٥ م/ثانية). نلاحظ تقارب النتائج العملية مع البرنامج المتطور والمتمثل بالنموذج ذو المعاملات الثلاثة وخصوصا في حالة كون الانفعالات الخطية التي اقل من (٠,٥). وفي النتائج نلاحظ كذلك إن معامل المرونة للمواد المرنة اللزجة والمواد المركبة متزايد بزيادة كلا من معدل الانفعال والزمن. النتائج العملية تمت مقارنتها مع النتائج العددية ولبعض الحالات البسيطات والتي أظهرت توافق كبير وذلك يشير إلى فعالية البرنامج المستخدم والمتمثل بـ (ansys program).