Poisson's Ratio as a Function of Time in Composite Material of Viscoelastic Behavior by Depending on Creep Test

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Abstract

In viscoelastic behavior of composite material, such as those made of thermo-set polyester and one layer random fiber glass, the Poisson's ratio is described in new function of time and stress. The relaxation stress is obtained experimentally to describe the non-linear viscoelastic behavior in composite material. The results show that, Poisson's ratio increases with an approximate rate of 16% as a result of the increasing stress from 6.877 MPa to 8.239 MPa and decreases with increasing the time at constant temperature 30 C^{o}.

The investigation demonstrated that such time dependence is not a necessary consequence of the theory of viscoelasticity to describe viscoelasticity behavior.

Keywords: viscoelastic behavior, composite material, thermo-set polyester, the relaxation stress.

نسبة Poisson's كدالة للزمن في المواد المركبة للسلوك اللزج المرن بالاعتماد على اختبار التزحيف

الخلاصة

السلوك اللزج–المرن للمواد المركبة مثل البوليستر المدعمة بطبقة من الألياف الزجاجية عشوائية التوزيع، وصفت نسبة(Poisson) في معادلة جديدة للزمن والإجهاد. أجهاد الاسترخاء تم حسابه عملياً لوصف السلوك اللزج–المرن اللاخطي في المواد المركبة. النتائج أظهرت ان نسبة (Poisson's Ratio) تزداد بنسبة تقريبية 16% نتيجة لزيادة الإجهاد من 6.877 MPa–8.239 MPa عند درجة حرارة ثابتة 30 درجة مئوية , كذلك يتناقص مع ازدياد الزمن. البحث الحالي يثبت انه ليس من الضروري تتبع خطوات نظرية اللزوجة–المرونة لوصف السلوك اللزج–المرن.

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List of symbols

Symbol	Definition	Unit
A(t)	Cross section area as function of time	mm^2
b(t)	Lateral dimension as function of time	mm
b_o	Initial lateral dimension	mm
E(ε,t)	Relaxation modulus	MPa
F	Force	N
L(t)	Longitudinal dimension as function of time	mm
ns(ε)	Slope of stress relaxation as function of strain	-----
n(σ)	Slope of creep strain as function of stress	----
t	Time	min
t_k	Thickness	mm
σ(t)	Stress relaxation as function of time	MPa
$\varepsilon_T(t)$	Lateral strain as function of time	mm
$\varepsilon_L(t)$	Longitudinal strain as function of time	mm
ν(t)	Poisson's ratio as function of time	-----

Introduction

Poisson 's ratio (ν) is a material constant for linear and nonlinear viscoelastic material and is defined as the negative ratio of the transverse strain (ε_T) to the longitudinal strain (ε_L) under uniaxial stressing in the longitudinal direction. For viscoelastic material (ν) is in general a time-dependent quantity.

In a viscoelastic material, a time-dependent Poisson's ratio will be associated with time-dependent stress and deformation, so stress concentration factor and interface stresses can depend on time[1,2].

In viscoelastic solids, the Poisson's ratio may be defined in several ways. Several authors have expressed concern about some definitions of Poisson's ratio [3]. For example, it is meaningful to consider the Poisson's ratio as ratio of the time-dependent transverse to longitudinal strain in axial extension, provided one recognizes the distinction between creep and relaxation.

As for experiment, the Poisson's ratio can be directly determined from the measured axial and transverse strains, or, in isotropic solids can be derived it from the time-dependent Young's and shear moduli. The experimental implications of the Poisson's ratio from direct or indirect data require high accuracy. It is difficult to directly measure the viscoelastic bulk modulus. Therefore, it is of interest to determine the bulk properties from the axial modulus and Poisson's ratio, which are easier to obtain [4]. LU et al. [5] stated that the Poisson's ratio must be determined to four significant digits to deduce the bulk modulus. Implication of the bulk modulus from the shear and axial modulus measurements requires high precision in the input data. The viscoelastic properties depend on temperature [6], therefore, input viscoelastic functions should be measured upon same specimen, in the same condition, at the same time, and with high accuracy and precision. In agricultural products, the time-dependent Poisson's ratio has not been extensively studied in the literature. However, a simple approach using a rapid mechanical method in relaxation tests was only applied for determining the Poisson's ratio by Hughes & Segrlind [7], and Segerlind & De Baerdemaeker [8]. However, these simplified tests give information that can be used to quantitatively determine the differences caused by factors such as variety, drying temperature, storage technique, maturity, and processing technique. The relaxation and creep tests provide the simplest and most direct technique to obtain mechanical properties involved in linear and nonlinear theory of viscoelasticity [9]

[10] Proposes a quasistatic method for Poisson's ratio estimation of isotropic acoustical porous materials. The method is based on longitudinal and transverse displacements measurements of a cylindrical sample.

Creep in the nonlinear zone of wood plastic composite can be described by a few material constants. The creep related material constants varied according to the stress level. The experiment was short term and the values of these constants will be used to characterize, simulate, and model long-term creep under varying temperature and moisture in our ongoing project.[11]

Analytical solution:

The hereditary elasticity (viscoelasticity) for composite material limited from creep test to get the empirical equation to describe the strain as function of time ε(t).i.e,[12]

$$E(t,\varepsilon_L) = E(\varepsilon_L) * t^{ns(\varepsilon_L)} \quad \text{.....(1)}$$

It can also be deduced from experimental results of stress relaxation as;

$$\sigma(t) = 10.3114 * t^{ns(\varepsilon_L)} \quad \text{.......(2)}$$

In creep, the load is constant (F=constant) therefore the cross section of creep specimen varies with time, A(t) and we can describe this variation can be described as follows:

$$A(t) = \frac{F}{\sigma(t)} \quad \text{...........(3)}$$

the variation in thickness of specimen (t_k) is neglected then the variation of cross section with time is attributed to variation in lateral dimension b(t) shown in figure(1-a).

Equation (3) can now be written as;

$$b(t) = \frac{F}{t_k\,\sigma(t)} \quad \text{..........(4)}$$

The stress can be calculated as;

$\sigma(t,\varepsilon)=Y^{*}\, t^{ns}$ ………..(5)

where:
$Y = 37.3585 * \varepsilon + 5.11381$
And,
$ns=-0.00328744-0.234139*\varepsilon +0.72606*\varepsilon^2$

The lateral strain can be calculated as;

$$\varepsilon_T(t)=\frac{b(t_2)-b(t_1)}{b_o} \quad \text{……..(6)}$$

where:
b_o is the initial dimension of creep specimen at time t=0.0

The variation in time longitudinal dimension, L(t), can be calculated as using the following equation:

$$L(t)=L(t_2)-L(t_1) \quad \text{……(7)}$$

where. The longitudinal strain can calculated as follows:

$$\varepsilon_L(t)=\frac{L(t_2)-L(t_1)}{L_o} \quad \text{……(8)}$$

Where. The transverse strain ε_T in terms of Poisson's ratio is written as[10]:

$$\varepsilon_T=-\nu\,\varepsilon_L=\frac{-\nu\,\sigma_L}{E} \quad \text{…….(9)}$$

Where, The time dependent Poisson 's ratio can be written as :

$$\nu(t)=-\frac{\varepsilon_T(t)}{\varepsilon_L(t)} \quad \text{………(10)}$$

Experimental work:

The type of reinforcement form that is used in the present study is a chopped fiber fabric form where (50 mm) long fibers are compressed together to form a randomly-oriented fiber fabric. The mechanical properties of this type of polyester resin and fibers are given in tables (1,2) [13].

For material whose creep response may be described by a separable time independent and time dependent strain, the following expression has often been found to yield a good description of creep of nonlinear viscoelastic materials at constant stress levels [14]:

$$\varepsilon_L(t)=\varepsilon_L(\sigma)\; t^{\,n} \quad \text{…….(11)}$$

from experimental investigation the longitudinal strain is described as follows,

$$\varepsilon_L(t)=0.07\; t^{\,n(\sigma)} \quad \text{………(12)}$$

where:

$n(\sigma)= - 0.012553 + 0.00589326 * \sigma - 0.000250162 * \sigma^2$ …….(13)

three creep tests at different levels are executed. they are used to evaluate the property of viscoelastic material. The dimensions of standard creep test specimen is shown in figure(1-b). According to reference [15].

The procedure used to execute the creep test involves reading the deformation of specimen at predetermined intervals. The strain of specimen is calculated during the time interval by the following simple strain formule and the results are shown in figure (2) :

$\varepsilon_L=\delta L/L_o$ …….. (14)

$\varepsilon_L(t)=\delta(t)/L_o$ ……. (15)

where t is the time elapsed in minutes,
$\varepsilon(t)$ is the instantaneous strain,
and L_o is the gauge length of the specimen in millimeters.
The value of $ns(\varepsilon)$ appears in Eq.(5) get from experimental data as follows:

$$ns(\varepsilon_L)=-0.00328744-0.234139*\varepsilon_L+0.72606*\varepsilon_L^2 \quad \text{……….(16)}$$

Figures(2) and (3) display the variation of strain variation with time in (log-log) relationship to limited the constants in that relationship $n(\sigma)$ and $\varepsilon_L(\sigma)$.
Figure (4) shows the variation of relaxation stress variation with time in log-log relationship to limited the constant of relaxation stress function $n_s(\varepsilon_L)$ and figure (5) describe the variation of relaxation stress with time.

Results and discussion:

A new relation for poisson's ratio as function of time and stress is developed from above mentioned analysis this relation is written as:

$$v(t,\sigma)=\frac{\dfrac{b(t_2)-b(t_1)}{b_o}}{0.07*t^{n(\sigma)}} \quad \text{…….(17)}$$

$$v(t,\sigma)=\frac{\dfrac{b(t_2)-b(t_1)}{b_o}}{0.07*t^{-0.012553+0.00589326*\sigma-0.000250162*\sigma^2}} \quad \text{..(18)}$$

Poisson's ratio decreases as time increases. As shown in figure (6). This behavior is due to the reduction in lateral strain (ε_T). The latter forces the thermo-set material to behave as a brittle one which increase the probability of failure.

In the thermo-set material have small change in lateral strain with time therefore the Poisson’s ratio decreasing as a results of small changed in lateral strain comparing with longitudinal strain shown in figure (7).

Conclusions:

From the experimental investigation of the present research work, a new formula for poisson's ratio as function of time and stress is developed. The material used in the research is a composite, thermoset polyester reinforced with randomly distributed fiber glass.
In thermoset material the time dependent longitudinal strain is greater than the corresponding lateral strain. It is found that the poisson's ration increases with an approximate rate of 16% as the stress increases from 6.877 MPa to 8.239 MPa. It is also found that poisson's ratio decrease as the time increase. If the variation in thichness (t_k) of the specimen is neglected, then the variation in cross section is attributed to the variation in the lateral dimension b(t) of specimen.

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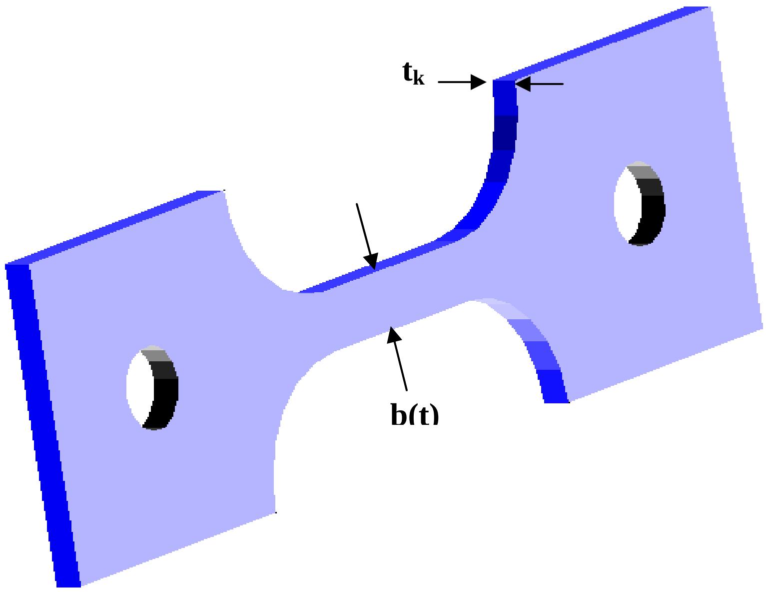
[15]Standard Creep Test ASTM-D2990.

Table (1) Mechanical Properties of Polyester resin [13]

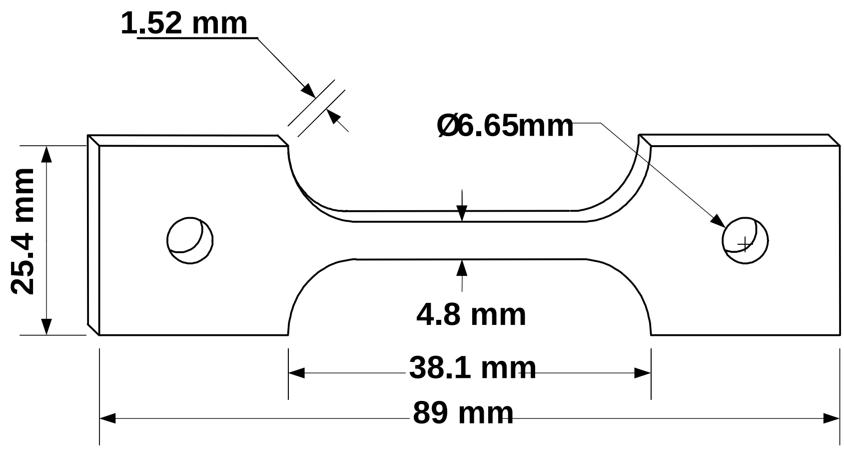
Properties	Value
Specific Density (at 20 C^o)	1.22
Tensile Stress at Break	65 N/mm^2
Elongation at break (50mm gauge length)	3.0 %
Modulus of Elasticity	3600 N/mm^2
Density (ρ)	1268 kg/m^3
Rockwell Hardness	M70

Table (2) Mechanical Properties of E-glass Fibers [13]

Glass type	Specific gravity	σ_{ult} (MPa)	Modulus of Elasticity (Gpa)	Liquids temperature °C
E-glass	2.58	3450	72.5	1065



a- Three dimensional creep specimen



b-Standard creep test specimen

Figure (1) Creep test specimen. [12]

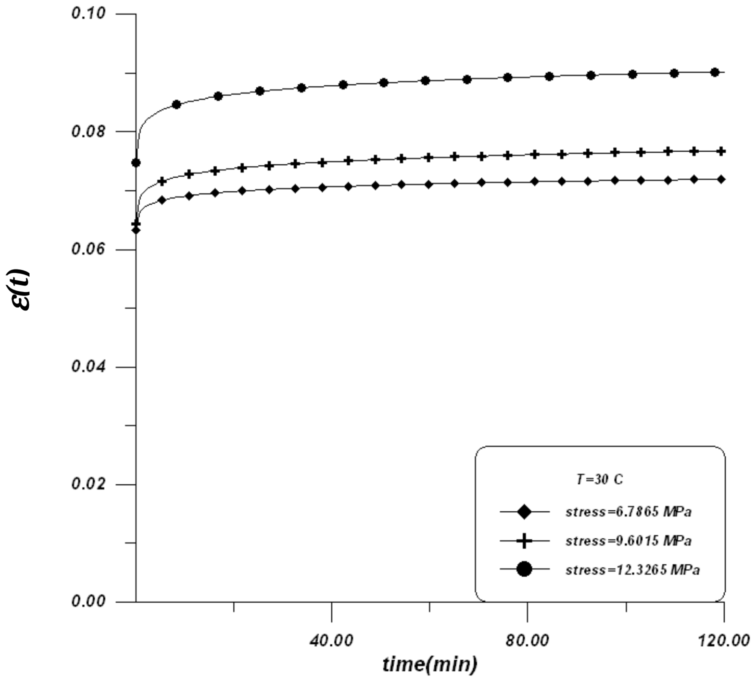


Figure (2)Experimental nonlinear creep for viscoelastic composite material

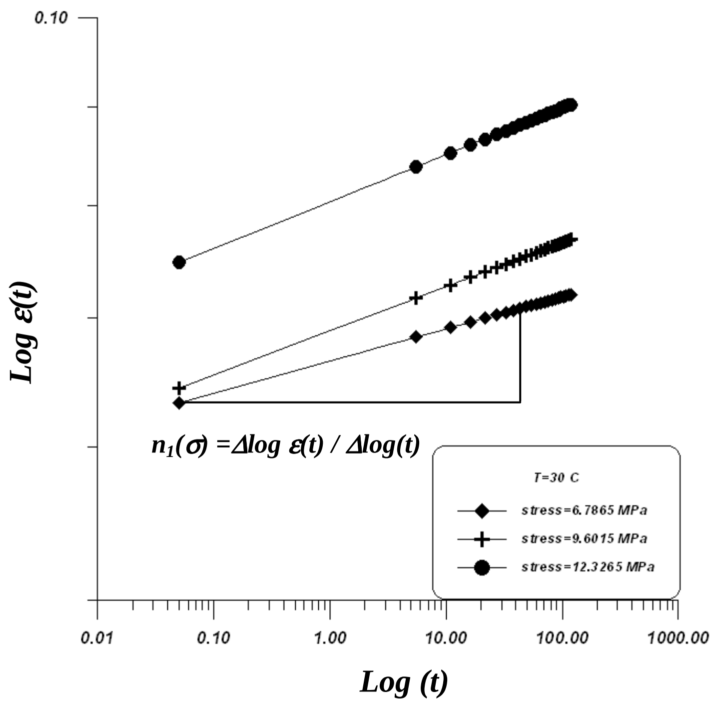


Figure (3) (log-log) Experimental nonlinear creep for viscoelastic composite material

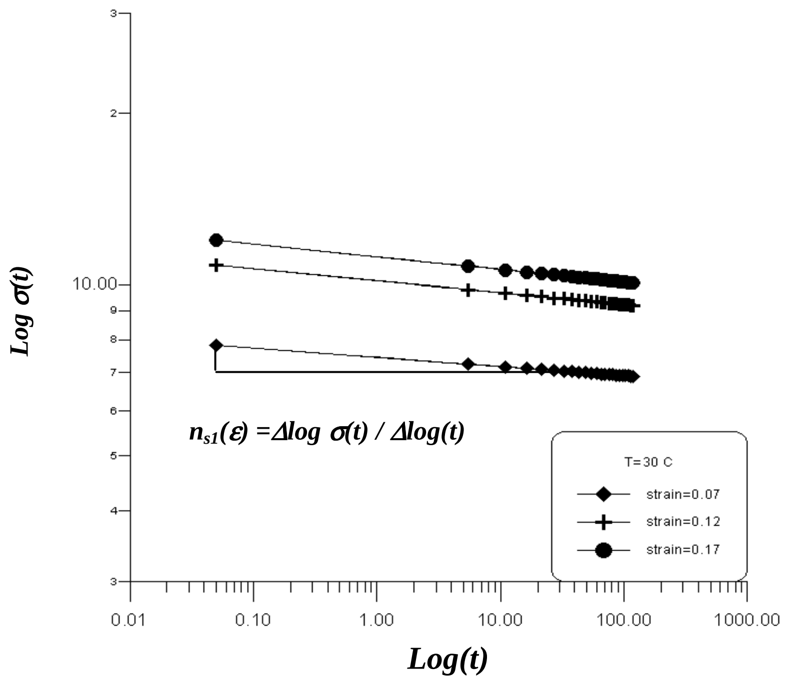


Figure (4) Log-Log stress relaxation for composite nonlinear viscoelastic polyester

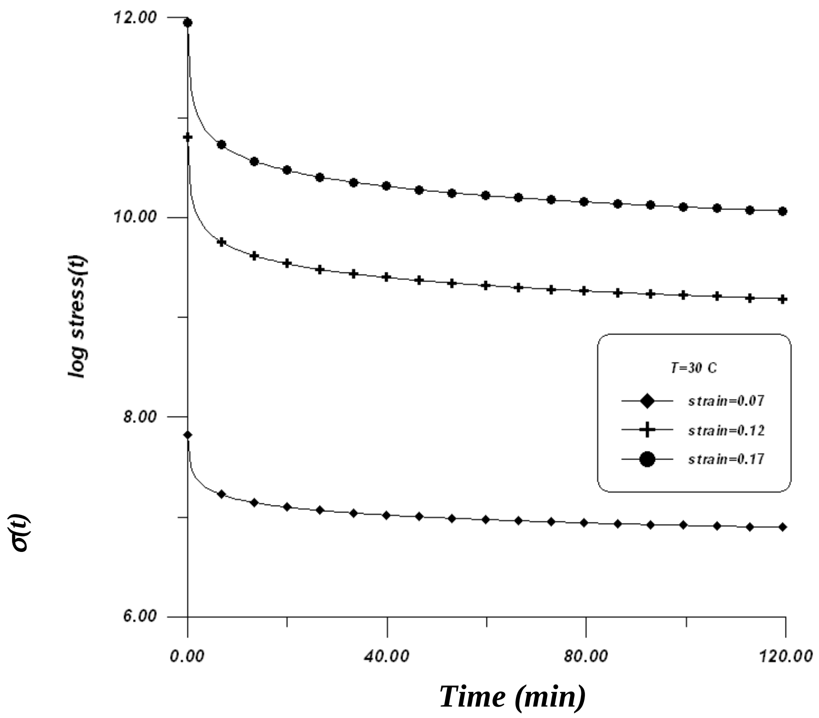


Figure (5) variation of stress relaxation of composite nonlinear viscoelastic polyester with time

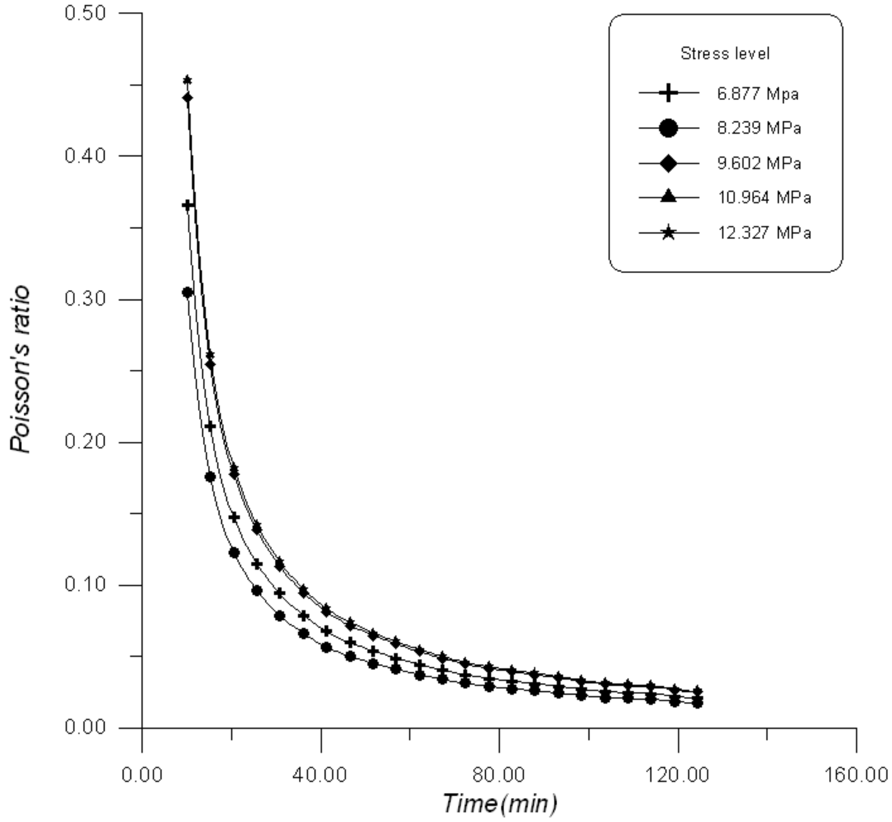


Figure (6) The relationship of Poisson's ratio with time

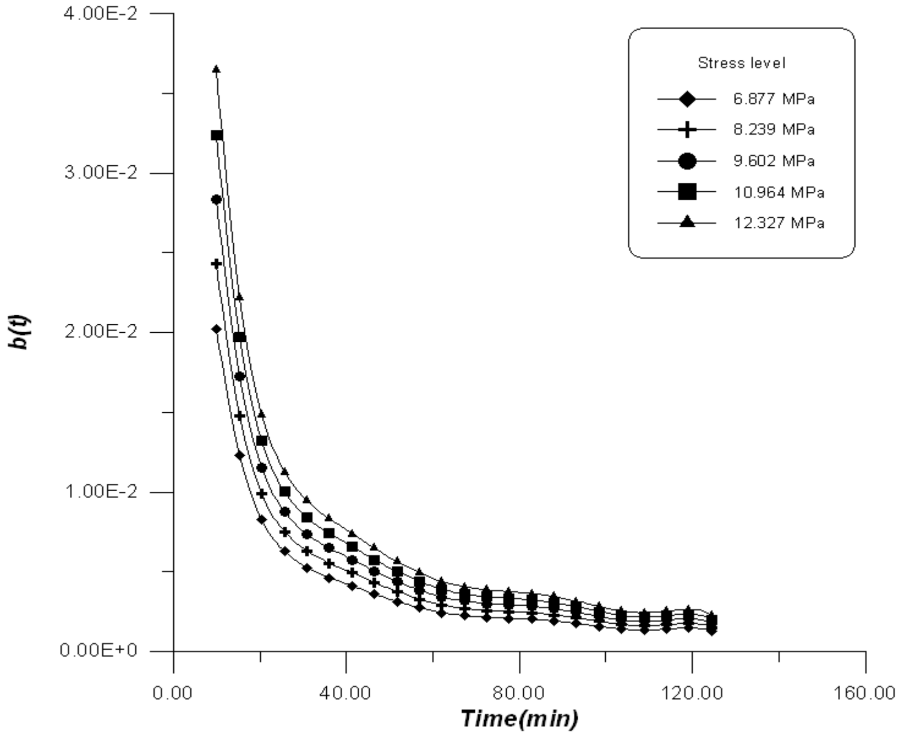


Figure (7) The relationship of variation of lateral strain b(t) with time