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The Time Dependent Poisson's Ratio of Nonlinear Thermoviscoelastic Behavior of Glass/Polyester Composite

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Abstract

The study predicted an equation describing the time-dependent Poisson's ratio by describing the nonlinear thermoviscoelastic behavior of the composite material depending on experimental results. The composite creep specimens are prepared from polyester resin reinforced with mat chopped. The experimental creep tests contribute to characterizing the behavior of nonlinear thermoviscoelastic material by determining relaxation stress as a function of time, strain, and, temperature. The Poisson's ratio was determined by taking into account the effect of temperature and time at different stresses. The creep tests were performed at various temperatures of 30, 40, 50, and, 60 C° and at different stresses which described the thermoviscoelastic behavior of the composite material. The study was concluded with a mathematical model to describe the Poison's ratio function, taking into consideration its effect on the thermoviscoelastic behavior of the composite material. The maximum effect of time on the Poisson's ratio was decreasing by an average ratio of 9.87% at a temperature of 60 C° and stress of 12.3MPa while the maximum effect of the temperature on Poisson's ratio was at an average ratio of 17.59% at a stress 12.3 MPa. In addition, the equation of Poisson's ratio $\nu(t, T)$ was found for the thermoviscoelastic behavior of the composite material. Finally, the mathematical model describes the failure behavior of the composite material used in the manufacture of tanks, boat hulls, and structures.

Keywords: Poisson's ratio, nonlinear, thermoviscoelastic.

Nomenclature

$\varepsilon(t,T)$	Strain as function of time and temperature	mm
T	Temperature	C°
$\varepsilon(\sigma)$	Time independent strain (function of applied stress).	
t	Time	min
A(t)	Cross section area as function of time	mm^2
F	Force	N
$\varepsilon_T(t,T)$	Lateral strain as function of time and temperature	mm
b(t)	Lateral dimension as function of time	mm
b_o	Initial lateral dimension	mm
L(t)	Longitudinal dimension as function of time	mm
L_o	the gauge length of the specimen in millimeters.	
$\varepsilon_L(t,T)$	Longitudinal strain as function of time and temperature	mm
$\nu(t,T)$	Poisson's ratio as function of time and temperature	-----
$\sigma(t,T)$	Stress relaxation as function of time and temperature	MPa
$ns(\sigma,T)$	Slope of creep stress as function of stress and temperature	----
$n(\sigma,T)$	Slope of creep strain as function of stress and temperature	----
$\nu(t, T)$	the Poisson's ratio as a function of time and temperature	
t	Time	min
t_k	Thickness	mm

1. Introduction

The mechanical behavior of polymeric materials is characterized by describing their time-dependent properties in shear or simple tension (creep). Global interest and growing demand for sustainable energy development lead to the preservation of future generations by preserving the environment and natural resources. Conservation of natural resources through improved mechanical properties and applications of multi-system components, such as composites and structural elements. Entire structures require further optimization of materials and a deeper understanding of the influence of temperature and pressure on time dependence [1]. The primary importance of the Poisson ratio lies in determining the mechanical properties of any material which can be found through experimental tests to measure the mechanical properties. Characteristics dependent on the Poisson ratio include plane fatigue, fracture stiffness, indentation resistance, acoustic wave propagation, thermal shock

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resistance, and critical torsion. In general, the Poisson ratio is treated as a parameter that varies from one polymer to another [2]. The study tested Poisson's ratio in three ranges of less than 0.2. Properties materials where the conventional elasticity is between (-1, 0.5). The study predicts the roots of the relationships of quadratic functions divided into three ranges ($-1< \nu \leq 0$), ($0\leq \nu \leq 0.2$), and ($0.2 \leq \nu <0.5$).The researchers investigated the three main issues in dealing with the calculation of the Poisson's ratio of polymers: anisotropy, strain dependence, and strain rate. They depend on mechanical properties, where they adopted an isotropic according to classical elasticity theory [3]. The study investigated materials, such as concrete and polymers under uniaxial load that exhibit creep under continuous axial load resulting in axial and transverse strain. They discussed the expected evolution concerning the time (increasing, decreasing, non-monotonic) of Poisson's viscous ratio[4]. The study determined the Poisson's ratio and Young modulus of red beans at different moisture levels and for a different loading rate, the study concluded that the Young modulus decreased with increasing the humidity percentage to predict the deformation behavior of red beans[5]. The study investigated the phenomenological relationships between Poisson's ratio of behavior and response materials under specific loading conditions. They analyzed different loading conditions on specimens and their effect on material properties. It included an inclusive study of the phenomenological relationships of the Poisson's ratio and the response, where the results confirmed that the Poisson's ratio adopts experimental results. They obtained two-dimensional (2D) strains under the influence of the process of creep or relaxation[6]. The researchers investigated the resistance of materials to deformation under mechanical loads rather than a change in volume as Poisson's ratio provides a measure of the performance of any material during strained elasticity. The study set numerical limits between (0.5 to -1) that are suitable for all isotropic materials. Through new experiments and methods leading to material synthesis, the Poisson ratio means an understanding of the mechanical properties of modern materials [7]. The researcher presented the definition of Poisson's ratio as an elastic constant representing the ratio of lateral contraction to elongation in the infinitesimal uniaxial extension of a homogeneous isotropic body. In viscoelastic materials, the Poisson ratio is a function of time that depends on the time system chosen to measure it[8]. The study presented that the Poisson ratio, in general, is a function that depends on time or a complex dynamic frequency that depends on its magnitude (in the frequency domain). The study presents that viscoelastic Poisson's ratio has a different time dependence based on the test method used. The relationship between Poisson's ratio in creep and relaxation can be developed. The viscoelastic Poisson's ratio does not need to be continuously increased over time and it does not have to be monotonic over time[9]. The study adopted the micro/Nanoindentation tester (NANOVEA) to find the modulus of elasticity, stiffness, and accumulation. Low carbon steel AISI1018, alloy steel AISI 4340, and, aluminum alloy 6061 were used as a case study. The study conducted a specific element analysis using a three-dimensional symmetric model to find a relationship between Poisson's ratio and material stress. The Poisson ratio was modeled from 0 to 0.48 to determine the effect of Poisson's ratio on the properties of the elastic-plastic where the properties were verified through the laboratory results. The study investigated that the Poisson's ratio is not considered to be physically stable in viscoelastic materials, but rather is a function that depends on time for polymeric. [10].The researchers developed a new 3D model of the thermoplastic viscoelastic behavior of unidirectional reinforced composite materials by applying Maxwell's model[11].The study investigated the determination of the viscoelastic behavior at different stress levels and the determination of the stress relaxation at different temperatures, Fancey’s latch model [12]. Concerning long-term tests, two widely accepted test methods are stress relaxation and creep [13–17].Changes in the mechanical properties of composite materials are related to changes in viscoelastic behavior [18-20] being mainly dependent on stress (creep) and strain (stress relaxation) levels and temperature. Differently from vegetable fiber-reinforced composites [18, 21], structural composites have microstructural changes related to the resin as a reflection of stress/strain variation. If the imposed stress/strain exceeds the maximum resistance of the composite, matrix/fiber de-bonding fiber breakage and destruction of matrix interlayers between fibers can occur.The study built a mathematical model to describe the problem of soft shells for the manufacture of composite materials for thin layers and to determine the deformation and residual stress [22]. They investigated the effect of Poisson's ratio and geometry on the stress concentration factor through triaxial stress on circular and square columns that have a U-notch. They described the elastic stress concentration as a function of Poisson's ratio.[23].The study examined polymers reinforced with short fibers at different periodic and constant loads and showed a decrease in the life of the polymer depending on the loading time and the amount of loading. The study concluded that it is possible to extend the life of failure with the development of rigidity of the compound by examining the damage path that can be used in predicting failure in reality [24]. The study examined four models of multi-layer of beams under constant stress to describe the viscoelastic behavior to limit the effect of the delamination fracture behavior [25].The study suggested a model based on Maxwell's model to show the effect of interior design factors on the viscoelastic-elastic relaxation coefficient E (t)[26]. The study investigated the physical aging of the viscoelastic behavior of epoxy material experimentally at different temperatures and times. The study showed that the aging shift factor is more affected by time than by temperature[27].The importance of the current study in describing the new mathematical model of the thermal viscoelastic behavior of composite materials used in tanks, boat hulls, and structures under constant stress over time and studying the effects of this behavior on the Poisson's ratio $\nu(t, T)$. In addition, the study determines the relaxation stress by taking into account temperature, stress, and strain. The aim of the present study is to describe the Poisson's ratio as a function $\nu(t, T)$ of the nonlinear thermoviscoelastic behavior of the composite material at different stresses according to ASTM creep specimens standard.

2. Theoretical Analysis

Mathematical models and in particular the energy function of time behavior describe the creeping behavior of viscoelastic materials with good accuracy and over a wide time range. The following mathematical model gives a good description of the creep of viscoelastic materials under constant stress[24]:

$$\varepsilon(t) = \varepsilon(\sigma).t^{n} \quad (1)$$

The time-dependent strain function $\varepsilon(t)$ can be determined by defining the variables involved in it by taking the logarithm of both sides of the equation, which results in a line graph having a slope representing the magnitude of the time-dependent strain equation constant. The viscoelastic behavior affected by temperature and the viscoelastic material properties, such as creep compliance, stress relaxation function, and the modulus of elasticity (E), is a function of time, strain, and temperature E(t, ε, T)[25]. As the applied load is constant during the creep process, the cross-section area of the specimens can be determined by [26]:

$$A(t) = \frac{F}{\sigma(t)} \quad (2)$$

in the creep test, the very small variation in thickness of specimens (t_k) is neglected, where the lateral strain b(t) represented a lateral strain of specimen cross-section $\varepsilon_T(t)$. The variation in the thickness of specimen (t_k) is neglected then the variation of the cross-section with time is attributed to variation in lateral dimension b(t) the equation (2) can now be written as; The lateral strain can be calculated as[27];

$$\varepsilon_T = \frac{b_2(t)-b_1(t)}{b_o} \quad (3)$$

The longitudinal strain can be calculated as follows;

$$\varepsilon_T = \frac{L(t_2)-L(t_1)}{L_o} \quad (4)$$

The transverse strain ε_T in terms of Poisson's ratio is written as[28]:

$$\varepsilon_T = -\nu.\varepsilon_L = \frac{-\nu.\sigma_L}{E(t,\varepsilon,T)} \quad (5)$$

The time depending on Poisson's ratio is determined by[28]:

$$\nu(t) = -\frac{\varepsilon_T(t)}{\varepsilon_L(t)} \quad (6)$$

3. Material And Methods

3.1. Material

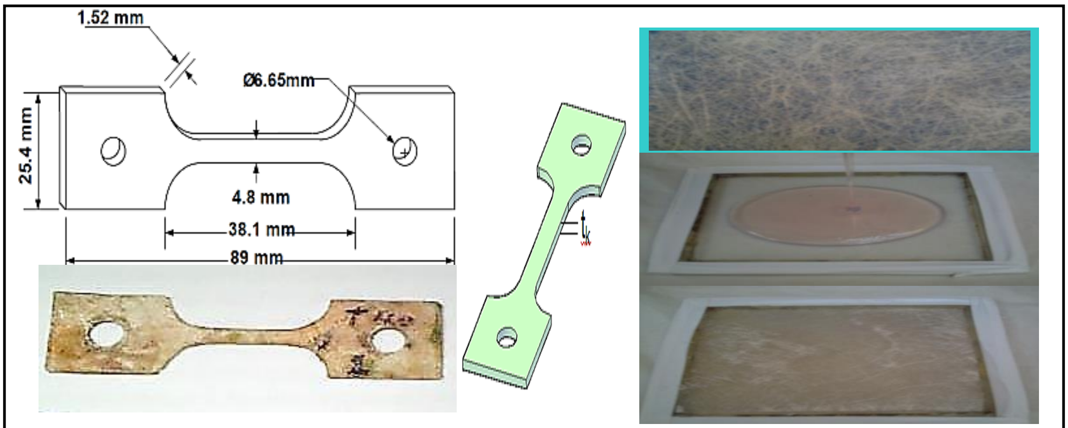
The study conducted experimental creep tests for a composite material consisting of polyester (matrix) that has properties shown in Table 1 and supported by random fiberglass (mat chopped) with specifications shown in Table 2 [29], with a volumetric fraction of 0.26 by determining the weight of the materials that consist of the composite material with additive hardener 0.01%, where the polyester was cast at room temperature. The creep specimens were cut using a CNC machine according to their standard dimensions. The research adopted creep specimens according to the standard creep test specimen (Standard Creep Test ASTM-D2990)[30] as shown inFigures1-a and b.

Table 1. Mechanical Properties of Polyester resin [29]

Properties	Value
Specific Density (at 20 C°)	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 [29]

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



a-The creep test **b- Preparing the composite material**

Figure 1. **a**-The Standard creep test specimen ASTM-D2990 [30]
b- Preparing the composite creep specimens

3.2. Methods

3.2.1. Nonlinear Behavior Of Composite Material

The study determined the range of non-linear behavior of the material by two creep tests required at a high-stress level, where the two creep tests do not satisfy the linear behavior of strain and stress conditions of the composite material as shown in equation (7) and (8), where the behavior of composite material will be considered nonlinear [31]:

$$\frac{\varepsilon_1(t_1)}{\sigma_1} = \frac{\varepsilon_2(t_1)}{\sigma_2} \quad (7)$$

$$\frac{\varepsilon_1(t_2)}{\sigma_1} = \frac{\varepsilon_2(t_2)}{\sigma_2} \quad (8)$$

The nonlinear thermoviscoelastic constitutive equation was derived using the concept of the linear principle, but it is extended to the nonlinear behavior range. Thermoviscoelastic has considered the response of viscoelastic material as very sensitive to the temperature variation uncounted in many engineering applications. The difficulty is mainly due to the nonlinear relationship between stress, strain, and, temperature. A method of direct experimental determines the kernel functions of the constitutive equation under variable loading, strain, and, temperature.

3.2.2. The Stress Relaxation

The relation between creep compliance and the stress relaxation function in viscoelastic behavior can be described by plotting the experimental data. Plotting the stress with time at different strains according to the log-log scale to find the slope of different strains n(ε). The stress relaxation can be expressed in the following equation [32]:

$$\sigma(t) = \sigma(\varepsilon).t^{n(\varepsilon)} \quad (9)$$

Stress relaxation is defined as a gradual decrease in stress with time under a constant strain. This behavior of composite is studied by applying a constant strain to the specimen and measuring the stress required to maintain that strain as a function of time [32] where relaxation stress was determined through the experimental results according to them the following equation at different strains and temperatures shown in (AppendixA):

$$\sigma(t,\varepsilon,T) = \sigma(\varepsilon,T).t^{ns(\varepsilon,T)} \quad (10)$$

Where,

$$\sigma(\varepsilon,T) = f_B(T).\varepsilon + f_A(T) \quad (11)$$

And ns(ε,T) as shown in (Appendix B)

$$ns(\varepsilon,T) = f_{ANS}(\varepsilon) + f_{BNS}(\varepsilon).T + f_{CNS}(\varepsilon).T^2 + f_{DNS}(\varepsilon).T^3 + f_{EDS}(\varepsilon).T^4 \quad (12)$$

The specimens have the rectangular cross-sectional area dependent on time and temperature during the creep test as the following:

$$A(t) = b(t,T).t_k \quad (13)$$

4. Results and Discussion

The complexity in describing the nonlinear thermoviscoelastic behavior of a composite material theoretically makes experimental results an appropriate way to predict this behavior in a mathematical model according to the specific conditions in which experimental tests were conducted, such as time, strain, and temperature. A new relation for Poisson's ratio as a function of time and stress is developed from the above-mentioned analysis. This relation of the thermo-time dependent Poisson's ratio can be written as the following [29]:

$$\nu(t,T) = -\frac{\varepsilon_T(t,T)}{\varepsilon_L(t,T)} \quad (14)$$

The variation in lateral dimension b(t). Equation (2) can now be written as [31];

$$b(t,T) = \frac{F}{t_k \, . \, \sigma(t,\varepsilon,T)} \quad (15)$$

The lateral strain can be calculated as [31];

$$\varepsilon_T(t,T) = \frac{b(t_2,T) - b(t_1,T)}{b_o} \quad (16)$$

Or, the transverse strain ε_T in terms of Poisson's ratio is written as [32]:

$$\varepsilon_T = -\nu\,\varepsilon_L = \frac{-\nu\,\sigma_L}{E} \quad (17)$$

Where, The longitudinal strain predicate by experimental results (Appendix C):

$$\varepsilon_L(t,\sigma,T) = \varepsilon(\sigma,T).t^{n(\sigma,T)} \quad (18)$$

Where,

$$n(\sigma,T) = f_{NA}(T) + f_{NB}(T).\sigma + f_{NC}(T).\sigma^2 \quad (19)$$

The results in Figure 2 show the effect of increasing the temperature on the Poisson's ratio, where it was found that Poisson's ratio increased by 16.15% when the temperature was raised from 30 C° to 60C°, so it was found that the maximum effect of increasing the time leads to a decrease of the Poisson's ratio by 8.15%at temperature 50 C° and stress 6.9 MPa. The Poisson's ratio decreases with time caused by a decrease in the transverse strain rate relative to the longitudinal strain in creep specimens due to the resistance of the composite material specimens with the time which agrees with the behavior of the Poisson's ratio in the study [31].

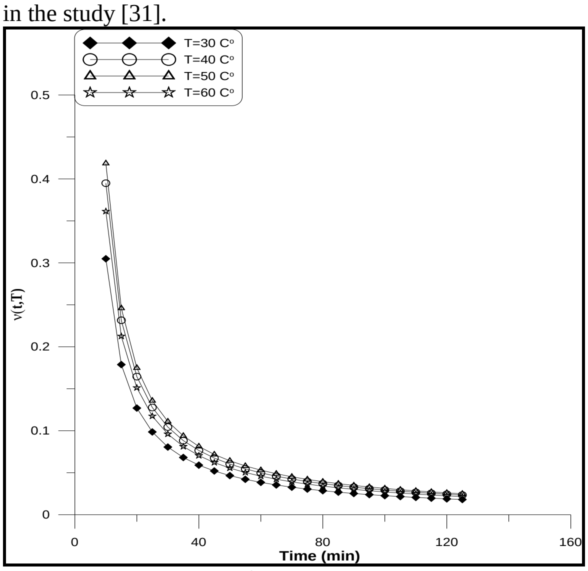


Figure 2. The relationship of the Poisson's ratio with time at stress 6.9 MPa and ε(T) is equal to 0.07 at different temperatures.

The results in Figure 3 showed an increase in the Poisson's ratio by an average ratio of 9.82% as a result of increasing the temperature from 30 C° to 60 C°at stress 8.24MPawhile increasing time leads to a maximum decrease in Poisson's ratio by 8.84% at temperature 40 C° and stress 8.24MPa.The Poisson's ratio increased with an average ratio of 9.82% as a result of increasing the temperature from 30C° to 60 C° and the maximum decrease in Poisson's ratio by 9.65% is due to increasing the time of applying the constant stress on the creep specimens at a temperature of 40 C° and stress of 9.6 MPa as shown in Figure 4.

The results in Figure 5 show the effect of increasing the temperature on the Poisson's ratio, where it was found that there was an increase of the Poisson ratio by an average ratio of 7.55% when the temperature was raised from 30 C° to 60C°at stress11 MPa, while Figure 6 presents the increase of Poisson's ratio by an average ratio of 10.26% as a result of increasing the temperature from 30 C° to 60 C° while maximum increasing of the time of applied stress leads to a decrease in Poisson's ratio by 25.9% at temperature 60 C° and stress 11 MPa, so it increases by 10.6% at temperature 50 C° and stress 12.3 MPa due to a decrease in the change ratio in the cross-section area of creep specimens.

The decrease in the change rate of Poisson's ratio is due to the decrease in the effect of raising the temperature with increasing the effect of the stress compared to the time effect on the specimens, which became the most effective factor in the events of longitudinal strain relative to the transverse. Comparing the experimental results of Figures 2, 3, 4, 5, and 6 show increasing the stress from (6.9 to 12.3) MPa to an increase in the Poisson's ratio with ratios (15.5%, 9.41%, 6.71%, 7.26%, and, 10.4%) at different temperature with fixing ε(T)at 0.12.Because the increase in stress causes an increase in the transverse strain of creep specimens relative to the longitudinal strain due to increasing the Poisson's ratio, which refers to the start of occurrence in the failure. In a specific period of time before failure, an increase in the transverse strain occurs more than in the longitudinal strain which is a symmetry to the necking phenomenon behavior in ductile materials, thus it can be considered as an indicator of starting failure occurrence of the composite material having the same composition. The change in the longitudinal and transverse strain depends on the movement of dislocations in the internal structure of the composite material specimens with the duration of the stress applied to it in addition to the temperature factor.

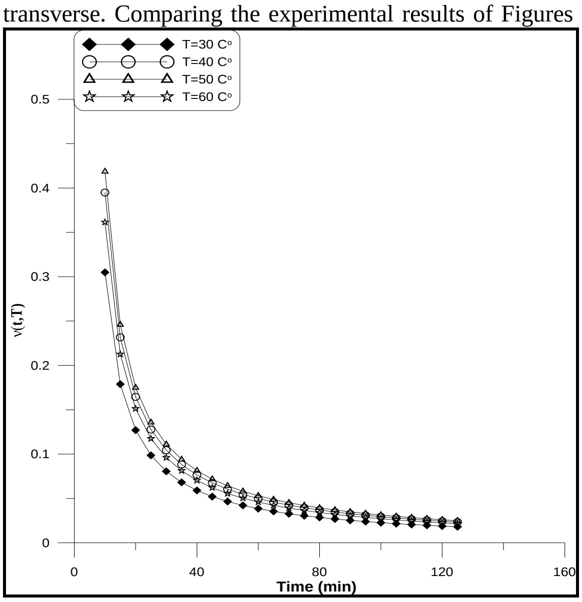


Figure 3. The relationship of the Poisson's ratio with time at stress 8.24 MPa and ε(T) is equal to 0.07 at different temperatures

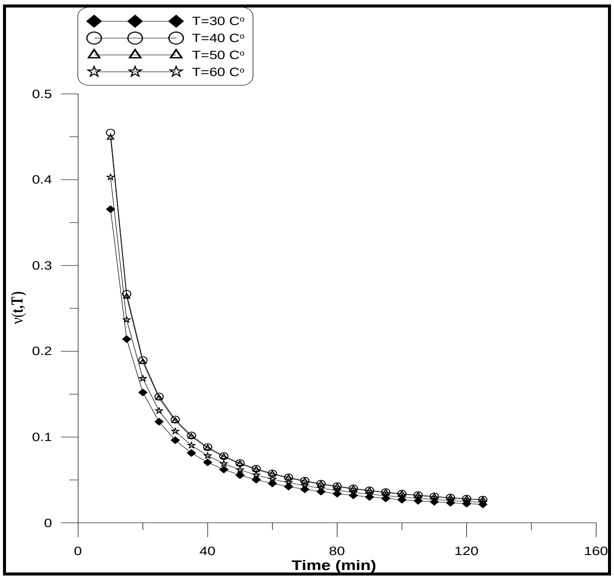


Figure 4. The relationship of the Poisson's ratio with time at stress 9.6 MPa and ε(T) is equal to 0.07 at different temperatures

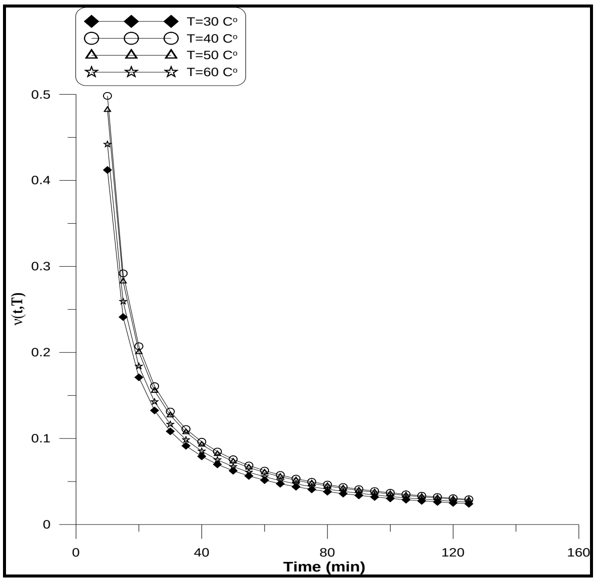


Figure 5. The relationship of the Poisson's ratio with time at stress 11 MPa and ε(T) is equal to 0.07 at different temperatures

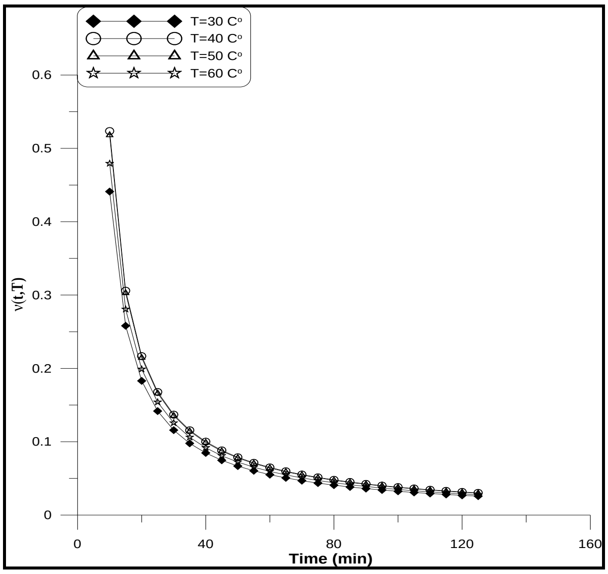


Figure 6. The relationship of the Poisson's ratio with time at stress 12.3 MP andε(T) is equal to 0.07 at different temperatures

Comparing the results in the Figures 7, 8, 9,10, and 11 it appears that the increase in the Poisson's ratio by 15.2%, 9.31%, 6.42%, 7.96%, and 10.1% when increasing the stresses from 6.9 to 12.3MPaof different temperature at fixing ε(T)at 0.12.The behavior of the material in changing the Poisson ratio, which depends on the instantaneous rate of change in the cross-section area of the specimens, which increases at first of loading and then decreases due to the movement of dislocations in the microstructure in the composite material and the redistribution of stress concentration in it, followed by limited increase before the final failure occurs.

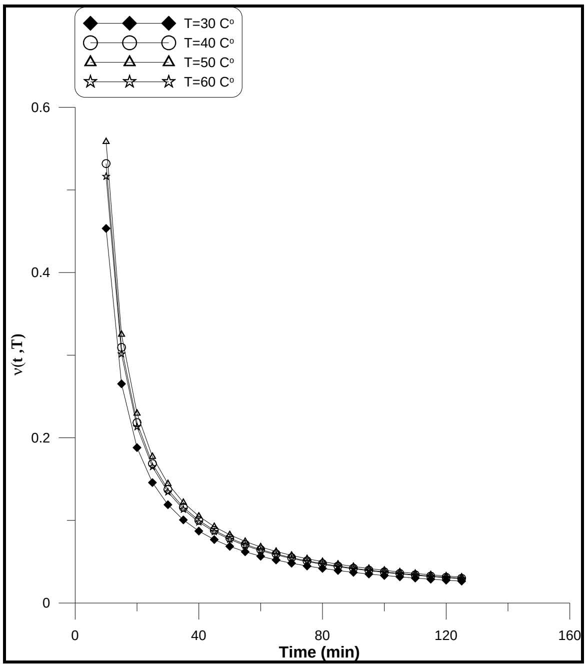


Figure7. The relationship of the Poisson's ratio with time at stress 6.9 MPa and ε(T) is equal to 0.12 at different temperatures

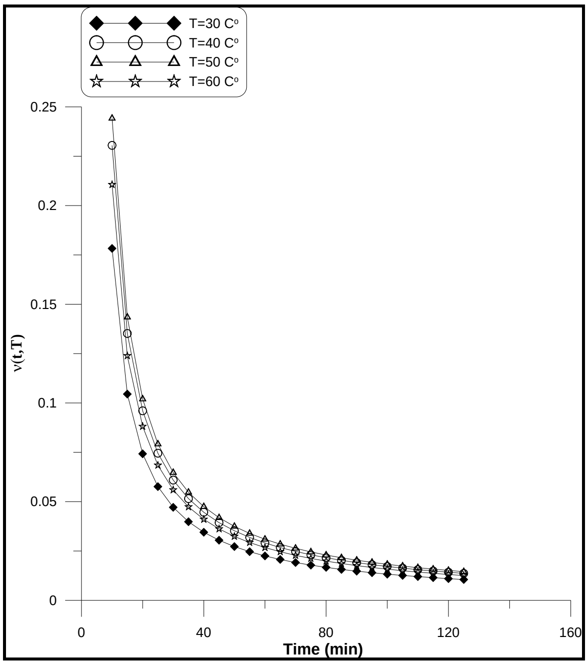


Figure 8 . The relationship of the Poisson's ratio with time at stress 8.24 MPa and ε(T) is equal to 0.12 at different temperatures

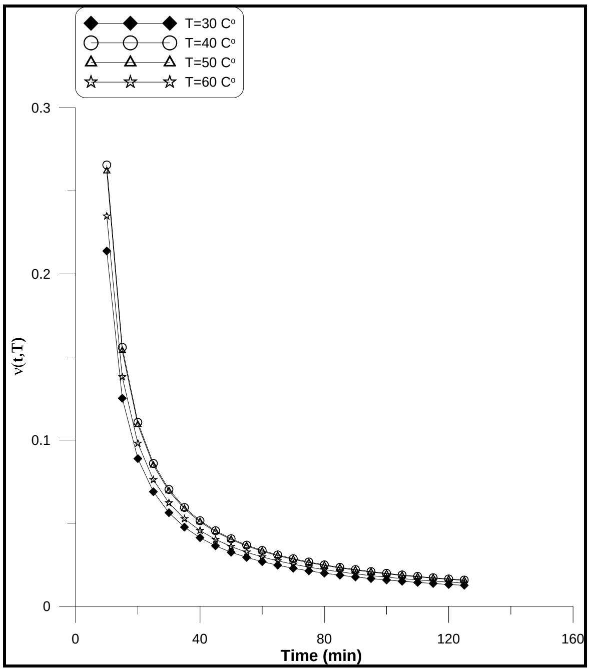


Figure 9. The relationship of the Poisson's ratio with time at stress 9.6 MPa and ε(T) is equal to 0.12 at different temperatures

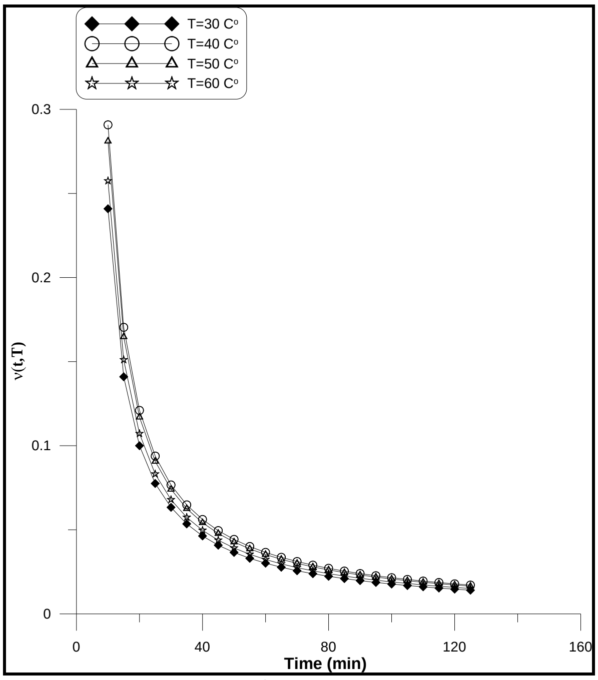


Figure10. The relationship of the Poisson's ratio with time at stress 11 MPa and ε(T) is equal to 0.12 at different temperatures

The experimental results in Figures 12, 13, 14, 15, and 16 describe the vary the increasing ratio of Poisson ratio which starts increasing then decreasing followed by limited increasing refer to the failure start occur in creep specimens.The Poisson ratio of different temperatures increased with ratios of 15.5%, 9.44%, 6.74%, 7.28%, and 10.4% as a result of increasing the stress from 6.9 to 12.3MPa at fixing ε(T)at 0.17.

The results in Figure17 display The effect of stress on Poisson's ratio at a temperature of 30 Cº. It was found that the Poisson's ratioincreases by 15.5 %while increasing with a ratioof 9.47 % as shown in Figure 18 at a temperature of40Cº when stress increases from 6.9 MPa to 12.3 MPa.

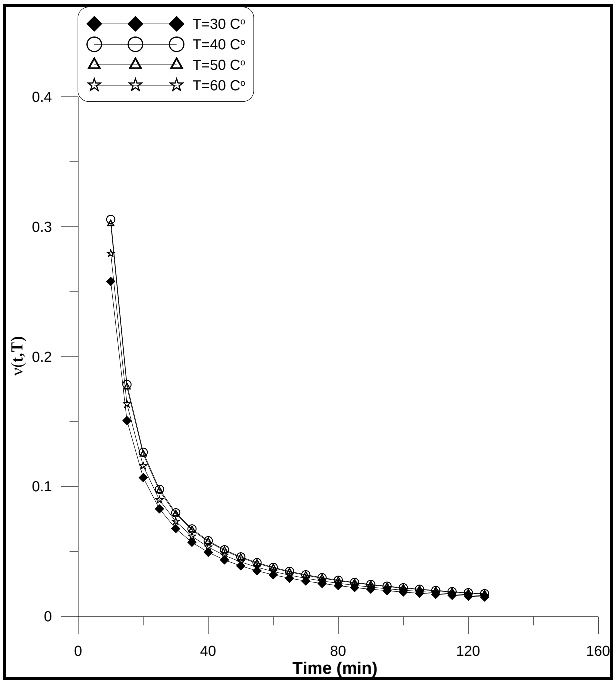


Figure 11. The relationship of the Poisson's ratio with time at stress 12.3 MPa and ε(T) is equal to 0.12 at different temperatures

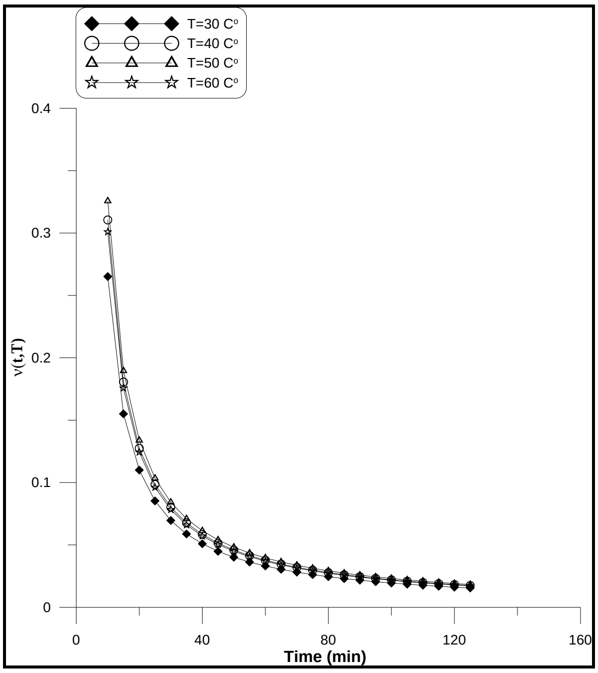


Figure 12 . The relationship of the Poisson's ratiowith time at stress 6.9 MPa and ε(T) is equal to 0.17 at different temperatures

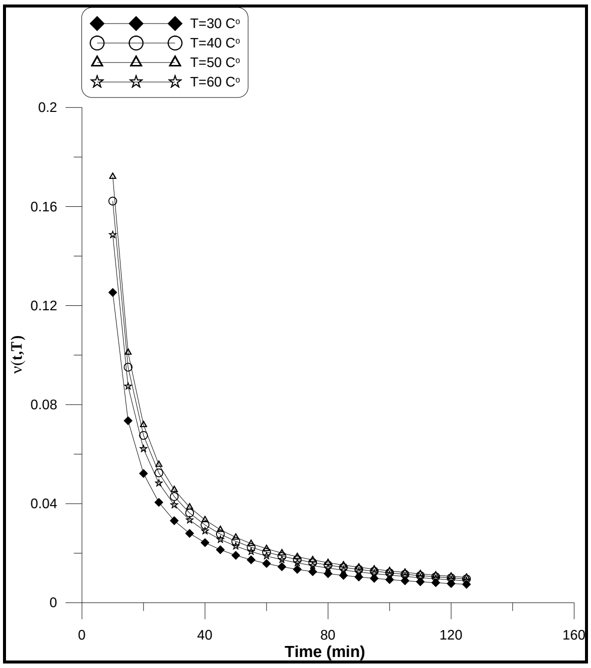


Figure 13 . The relationship of the Poisson's ratiowith time at stress 8.24 MPa and ε(T) is equal to 0.17 at different temperatures

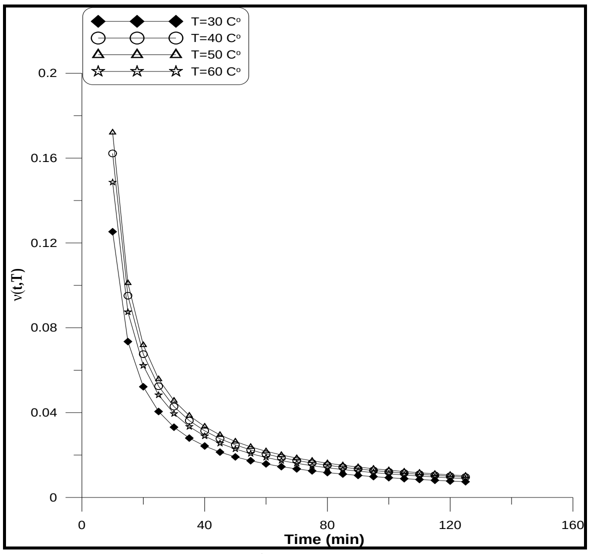


Figure 14. The relationship of the Poisson's ratiowith time at stress 9.6 MPa and ε(T) is equal to 0.17 at different temperatures

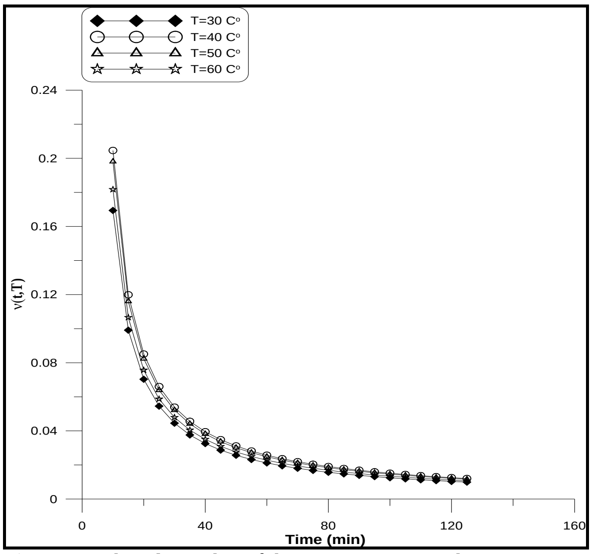


Figure 15. The relationship of the Poisson's ratio with time at stress 11 MPa and ε(T) is equal to 0.17 at different temperatures

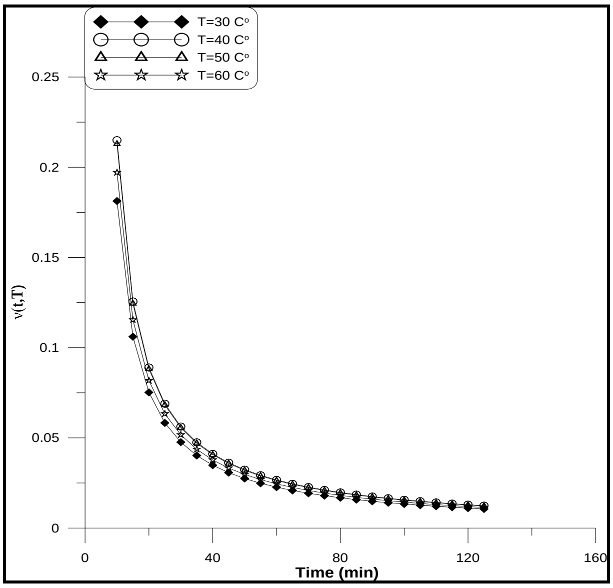


Figure 16. The relationship of the Poisson's ratio with time at stress 12.3 MPa and ε(T) is equal to 0.17 at different temperatures

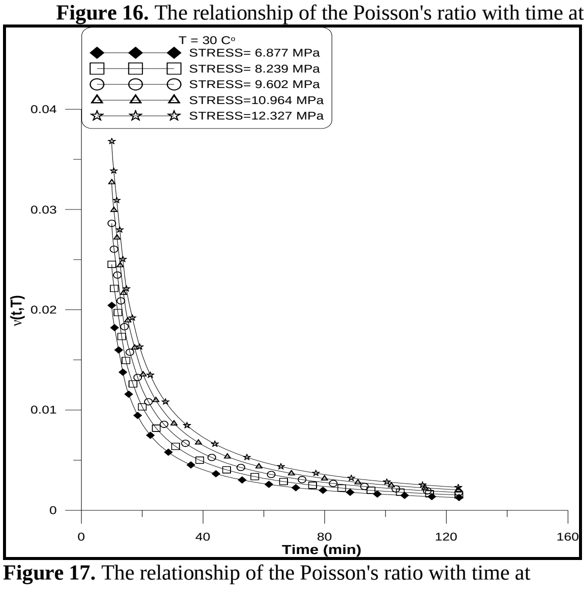


Figure 17. The relationship of the Poisson's ratio with time at temperature 30 and ε(T) is equal to 0.07 at different stresses

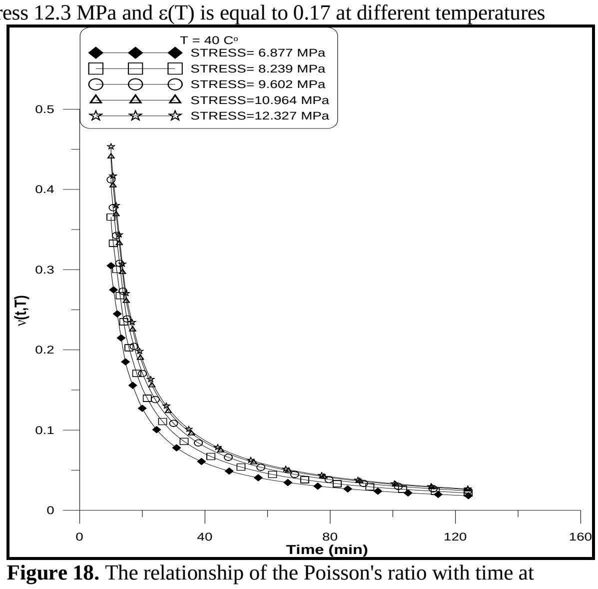


Figure 18. The relationship of the Poisson's ratio with time at temperature 40 C° and ε(T) is equal to 0.07 at different stresses

Figure19 displays The effect of stress on Poisson's ratio at a temperature of 50 Cº. It was found that the Poisson's ratio increases by 7.2 % while increasing with a ratio of 10.2 % as shown in Figure 10at temperature 60 Cº when stress increases from 6.9 MPa to 12.3 MPa when fixing ε(T)at 0.07.

The three-dimensional Figure21 showed the effect of temperature on the Poisson's ratio as a function of time ν(t, T) at stress 6.9 MPa. The decrease in the change of the Poisson's ratio over time is due to the material's resistance to elongation as a result of the rearrangement of dislocations movement in the microstructure of the composite material specimens, while the effect of increasing the temperature from 30 Cº to 50 Cº leads to increase the Poisson's ratio by 27.5%and followed by decreasing with ratio 15.6 % in the interval between 50 Cº to 60 Cºwith fixing ε(T)at 0.07.

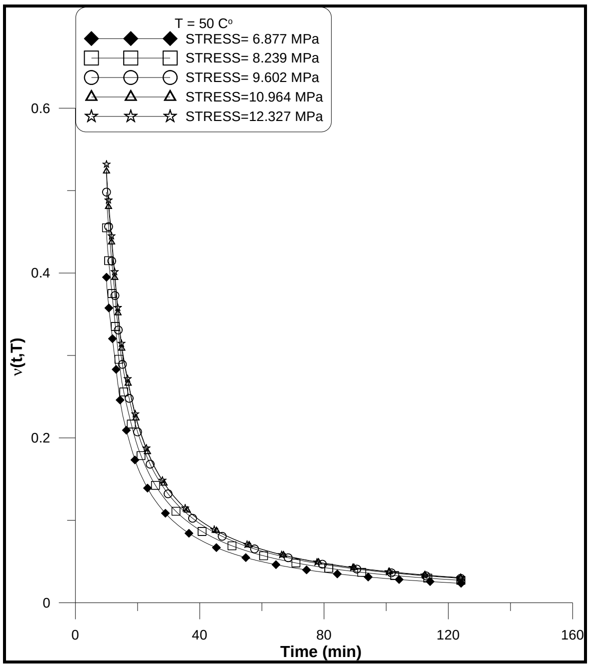


Figure 19. The relationship of the Poisson's ratio with time at temperature 50 Cºand ε(T) is equal to 0.07 at different stresses

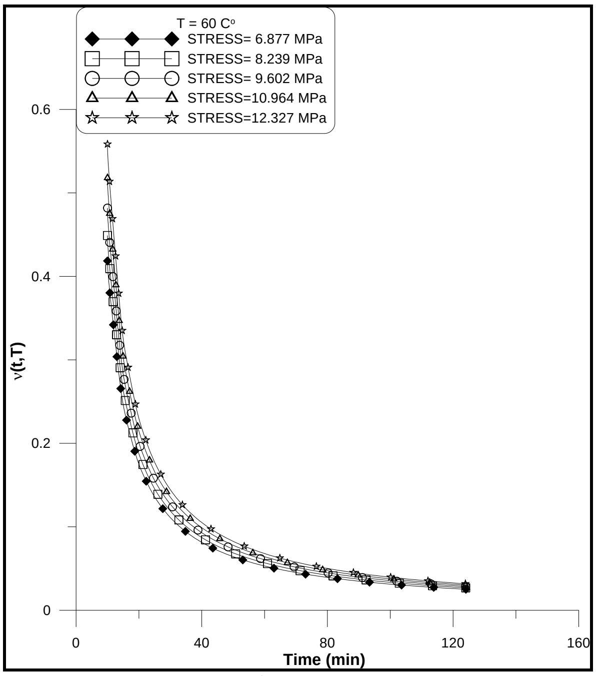


Figure 20. The relationship of the Poisson's ratio with time at temperature 60 Cºand ε(T) is equal to 0.07 at different stresses

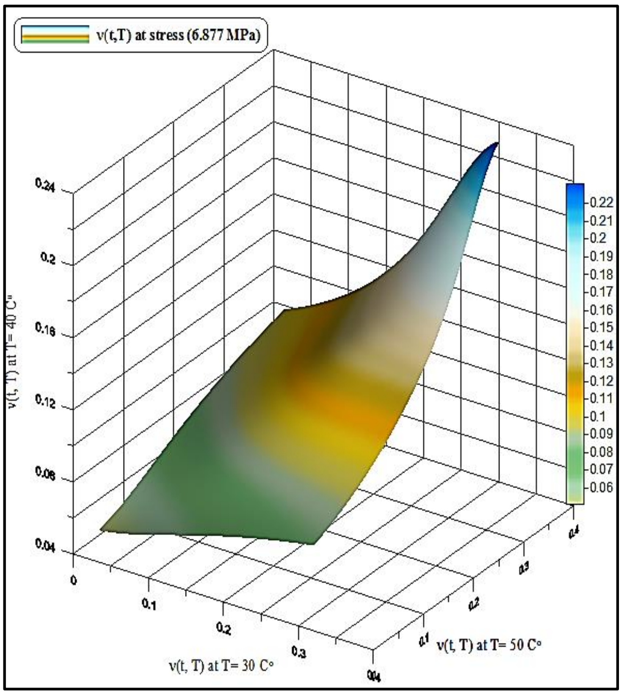


Figure 21. The relationship of the Poisson's ratioν(t,T) with time and Temperatureat stress 6.9 MPa

The three-dimensional figure shows the effect of both time and temperature between 30 to 50 Cº at a stress of 8.24MPa which increases in Poisson's ratio by 19% followed by decreases in a ratio of 10.25% in the range of temperature between 50 Co to 60 Cº. The occurrence of a decrease in the Poisson ratio indicates a decrease in the transverse strain compared to the longitudinal strain, which is an indicator of the start of failure. The value of the Poisson's ratio ν (t, T) is between (0.06) and its highest value (0.21). The figure shows the overlapping effect of increasing the temperature and time, which leads to an increase in the value of the Poisson's ratio that occurs due to the increase in the transverse strain in the test samples before the fracture occurs, as shown in Figure 22. Meanwhile, the effect of increasing temperature from 30 to 50 Cºleads to an increase in the Poisson's ratio by 14.7% at stress 9.6 MPa as shown in Figure 23.

The 3-Dimensional Figure24 showed the effect of increasing the temperature from 30 Cº to 50 Cº leads to an increase in the Poisson's ratio by an average ratio of 7.88% at stress 11 MPa,while the Poisson's ratio increased by an average ratio of 17.59% at stress 12.3 MPa as shown in Figure 25.

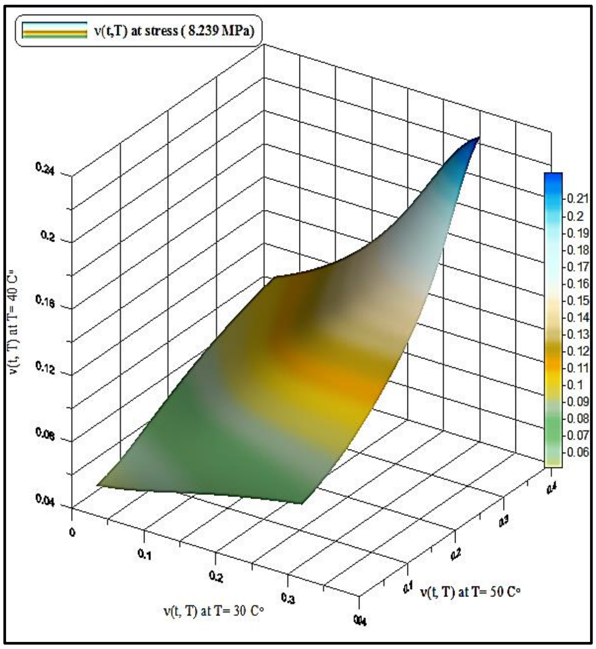


Figure 22. The relationship of the Poisson's ratio ν(t, T) with time and Temperature at stress 8.24 MPa

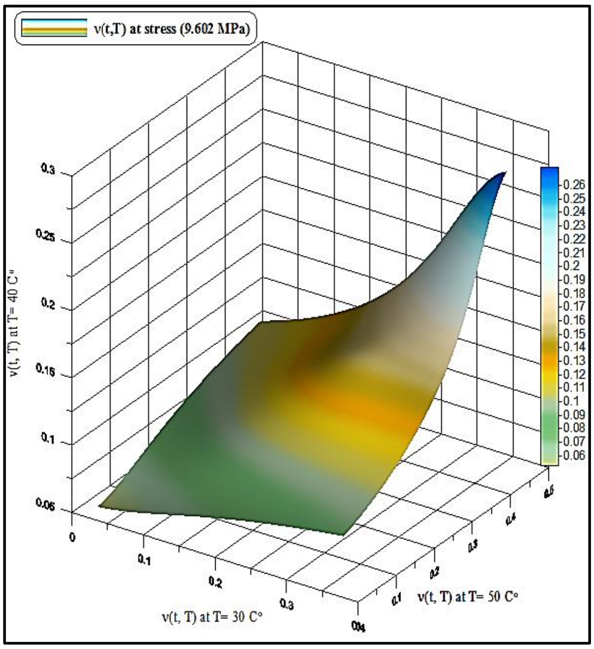


Figure 23. The relationship of the Poisson's ratio ν(t, T) with time and Temperature at stress 9.6 MPa

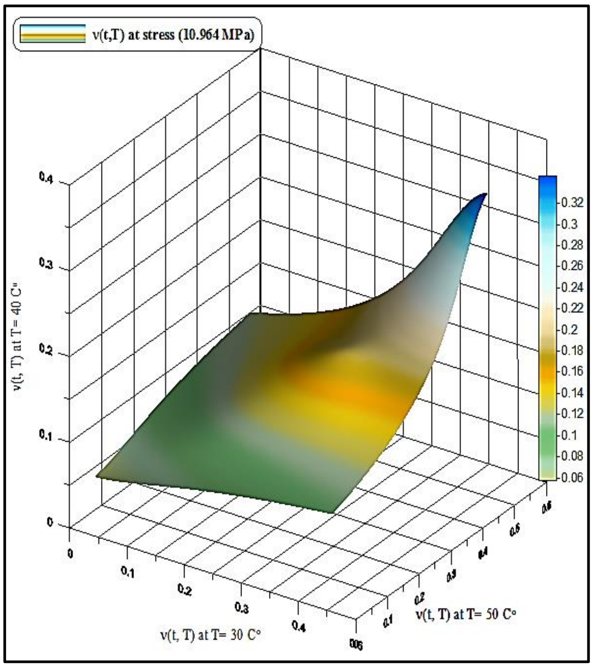


Figure 24. The relationship of the Poisson's ratio ν(t, T) with time and Temperature at stress 11 MPa

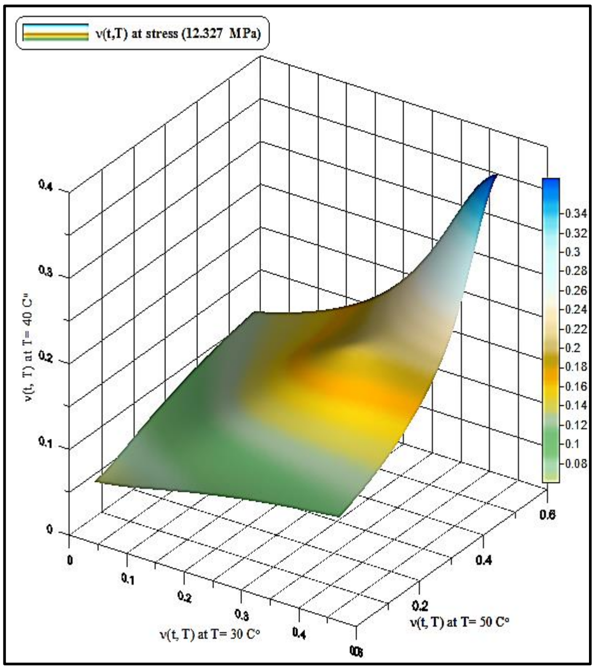


Figure 25. The relationship of the Poisson's ratio ν(t, T) with time and Temperature at stress 12.3 MPa

In the above three-dimensional figures, it is observed that there was an increase in the Poisson's ratio at temperature40 C^o compared to the smooth rise in it at other temperatures, as there was an increase in the Poisson's ratio with applying the stress giving the composite specimens the suitable time to gain maximum elongation strain through a creep test. Figure 26 shows the decrease in the percentage change occurring in the Poisson's ratio, which is a function of time and temperature with an increase in stress since the decrease in stress gave the specimen the necessary time for longitudinal elongation before the failure occurred. The lowest change occurred in the Poisson's ratio at stress 11 MPa, where the specimen reached its maximum resistance to prevent the occurrence of failure, followed by a slight increase in the change at stress 12.3 MPa which is considered the stress that will lead to failure and the increase resulting from the internal redistribution of stresses in the specimen due to a higher dislocation movement in the creep test of the composite specimens and then failure occurs.

The study found that the maximum effect of time on the Poisson's ratio ν(t, T) was at the time in the range of 10-60 minutes and led to a decrease in the Poisson's ratio by a ratio of 9.87% due to an increase the amount of instantaneous change in cross-section area of creep specimens at temperature 60 C^o and stress12.3MPa. The maximum effect of the temperature on Poisson's ratio was at an average ratio of 17.59%at stress 12.3MPa.The highest effect of stress on Poisson's ratio was an increase of 33.44% as a result of increasing stress in intervals between 11MPa to 12.3MPa when temperature 30 C^o and strain 0.12.It was observed that the decrease in the effect of increasing the temperature and stress on Poisson's ratio is an indication of the beginning of failure in the composite specimens during the creep test, especially at intervals between 50 to 60 C^o.

Conclusions

The conclusion of the research is to build a mathematical model describing the Poisson's ratio ν(t, T) as a function of the time and temperature of composite materials. The study found the maximum effect of the temperature on Poisson's ratio was at 17.59% at stress 12.3MPa at a time of 30 minutes so that, the Poisson's ratio increased by a maximum ratio of 2.77% when the stress increased by 16.53% which mean that the temperature's effect 6.3 times of the stress's effect at this condition. The experimental results refer to the maximum increase ratio that occurred in the Poisson's ratio by an increase of 33.44% as a result of increasing stress in the interval between 11 MPa to 12.3MPa when temperature 30 C^o and strain 0.12. Finally, the mathematical model covers a wide range of cases to describe the behavior of the composite material at constant loads with time to predict the time of failure in it from the change that occurs in Poisson's ratio ν(t, T) that are used in the manufacture of tanks and structures.

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Figure 26. The relationship of average change of Poisson's ratio $\Delta\nu$(t, T) at different stresses

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Appendices

Appendix–A. The experimental function of stress as a function of strain and temperature

$$f_B(T) = -4041.75 + 484.083.T - 18.3113\,.T^2 + 0.28793\,.T^3 - 0.00161287.T^4 \quad \text{(A.1)}$$

$$f_A(T) = 496.922 - 52.069.T + 1.87278\,.T^2 - 0.0284644\,.T^3 + 0.000155193.T^4 \quad \text{(A.2)}$$

$$\sigma(\varepsilon, T) = f_B(T).\varepsilon + f_A(T) \quad \text{(A.3)}$$

Appendix–B. The experimental fitting of (ns) which is the slope of logarithm of stress as a function of strain and temperature

$$f_{ANS}(\varepsilon) = 2.89798 - 64.9958\,.\varepsilon + 252.399.\varepsilon^2 \quad \text{(B.1)}$$

$$f_{BNS}(\varepsilon) = -0.252621 + 5.59588\,.\varepsilon - 21.305.\varepsilon^2 \quad \text{(B.2)}$$

$$f_{CNS}(\varepsilon) = 0.008076 - 0.176779.\varepsilon + 0.658348\,.\varepsilon^2 \quad \text{(B.3)}$$

$$f_{DNS}(\varepsilon) = -0.000113913 + 0.00245404\,.\varepsilon - 0.00896002.\varepsilon^2 \quad \text{(B.4)}$$

$$f_{ENS}(\varepsilon) = 5.98297\text{E} - 007 - 1.26821\text{E} - 005.\varepsilon + 4.55375\text{E} - 005.\varepsilon^2 \quad \text{(B.5)}$$

$$ns(\varepsilon, T) = f_{ANS}(\varepsilon) + f_{BNS}(\varepsilon).T + f_{CNS}(\varepsilon).T^2 + f_{DNS}(\varepsilon).T^3 + f_{ENS}(\varepsilon).T^4 \quad \text{(B.6)}$$

Appendix–C. The experimental fitting of the strain as a function of strain, stress, and, temperature

$$f_{NA}(T) = -7.36306 + 0.63538.T - 0.0201105.T^2 + 0.000280252.T^3 - 1.45469\text{E} - 006.T^4 \quad \text{(C.1)}$$

$$f_{NB}(T) = 1.71764 - 0.146934.T + 0.00460911.T^2 - 6.35792\text{E} - 005.T^3 + 3.2681\text{E} - 007.T^4 \quad \text{(C.2)}$$

$$f_{NB}(T) = -0.0852624 + 0.00719369.T - 0.000222179.T^2 + 3.02208\text{E} - 06.T^3 - 1.535\text{E} - 008.T^4 \quad \text{(C.3)}$$

$$n(\sigma, T) = f_{NA}(T) + f_{NB}(T).\sigma + f_{NC}(T).\sigma^2$$

$$\varepsilon(t, \sigma, T) = \varepsilon(\sigma, T).t^{n(\sigma, T)}$$