



The Effect of Fiber-Adhesive Composite on Bond Strength of Plastic Plates- Part IV: The Effect of Temperature on the Mechanical Behavior and Mechanical Properties

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ABSTRACT: The aim of this study is to use reinforced plastic composite for natural gas transportation at high temperature and pressure. The reinforced plastic composite is extensively used in many industries. In this work, the effect of temperature on PVC/PVC sandwich plates containing 0.95 Wt.% glass fiber and blended with different adhesives (epoxy, polyester, and polyvinyl chloride) is studied. Different temperatures (35 °C, 45 °C, 55 °C, 65 °C, and 75 °C) and three exposure times (2, 4, and 6 Hrs) are used. The mechanical properties, such as tensile strength, ultimate strength, modulus of elasticity, fracture energy, impact energy, and adhesion shear at different temperatures, are studied. The activation energy of PVC/PVC sandwich plates reinforced with glass fiber and blended with different adhesives was studied. It has been found that the mechanical properties of PVC/PVC sandwich plates containing 0.95 Wt.% glass fiber and blended with different types of adhesives are affected by temperature. In addition, it has been found that the activation energy of PVC/PVC sandwich plates reinforced with glass fiber and blended with polyvinyl acetate is the highest among epoxy and polyester. Based on the results obtained from the experiments, it has been found that the mechanical properties and high-temperature resistance of the PVC were significantly improved when adhesives and reinforcing materials were blended with the PVC.

Keywords: Activation energy, glass fiber, epoxy, polyester, polyvinyl acetate, temperature, PVC.

INTRODUCTION

The technological advances across various sectors have created demand for new materials that can perform under stringent conditions (high pressure and temperature, highly corrosive environments, and high-strength requirements), which conventional materials have failed to meet. Industry has recognized the ability of composite materials to produce high-quality, durable, and cost-effective products (Agbolaghi, 2018; Hulugappa et al., 2016; Z. Kaya et al., 2020; Ata et al., 2022). A composite material is a material that consists of two or more physically distinct phases, suitably arranged or distributed (Khan et al., 2021). The continuous phase is referred to as the matrix, while the dispersed phase is called the reinforcement (Robinson et al., 2017). Composite materials based on a polymeric matrix exhibit mechanical properties that are strongly dependent on temperature and strain rate (Zeidi et al., 2021; F. Balıkoğlu et al., 2022). A sandwich-structured composite is a special class of composite material fabricated by attaching two thin, stiff skins to a lightweight, thick core. The core material is typically low-strength, but its greater thickness provides the sandwich composite with high bending stiffness and a low overall density (Balıkoğlu et al., 2022; G. Aklilu et al., 2021).

The greatest benefit of polymeric composite pipes to the chemical, petroleum, and processing industries is the reduction of capital costs and operating expenses. Polymeric composites offer many cost advantages over metals due to their considerably higher strength-to-weight ratio (Aklilu et al., 2021). Cost savings also occur when accessing remote locations and offshore applications

(Zheng Sun et al., 2022). In oil and gas pipelines, polymeric composites offer a cost advantage due to their excellent hydraulic characteristics and the lack of required hot work (e.g., welding, outdoor exposure). This increases safety by reducing the risk of accidents and incidents during hot work (Camelia Cerbu et al., 2020). The important mechanical properties of a composite pipe are strength, stiffness, and service life, which make it imperative to assess the leakage integrity and reliability of a piping system (Baghad et al., 2022; S. Mousavi-Bafrouyi et al., 2021). Thermoset piping system materials are a combination of resins and reinforcing materials. At present, composite pipes are being fabricated using glass fiber and an epoxy resin matrix by the filament-winding process using a 2-axis filament-winding machine (M. Elyoussef et al., 2020; Kimiyoshi Naito et al., 2022; Mahmood).

A glass-reinforced epoxy is lightweight, erosion-resistant, high-temperature-resistant, heat-conductive, stiff, and aesthetically pleasing. Epoxy glass has been the preferred reinforcing fiber. These reinforcing composites are crucial for enhancing corrosion resistance and extending the pipe's service life (Kumarasamy, S. et al., 2018; S. M. Shahabaz et al., 2021). Yang et al. (2018) studied the effect of temperature on the tensile mechanical properties of GFRP bars with different diameters; they found that the ultimate tensile strength decreases with increasing temperature from -20 °C to 300 °C (Fan Yang et al., 2018). M.Xian et al. (2020) studied the effect of temperature on the mechanical properties and polymerization kinetics of polyamide-6 composites, from the experimental and modeling results, it can be concluded that the optimal temperature for polymerization is 140–160 °C, and the molding process must be finished within 20 second regardless of the shapes and sizes of the samples (Mei-Xian Li, et al., 2020).

A. Anvari et al. (2020) studied the effect of temperature on the mechanical properties of carbon composites. They found that the interlaminar shear stress at the interface between single-walled carbon nanotubes and aluminum foam is higher than that at the interface between multiwalled carbon nanotubes and aluminum foam (Ali et al., 2020). Liang et al. (2022) studied the influence of preheating temperature on the mechanical properties of injection-overmolded hybrid glass fiber-reinforced thermoplastic composites. The experimental results reveal that the surface roughness of the organosheet increases with increasing preheating temperature, resulting in enhanced mechanical interlock at the bonding interface (Liang et al., 2022). The effect of temperature on the mechanical properties of modified polypropylene: they found that both the yield stress and the elastic modulus decrease with increasing temperature. The properties are also significantly influenced by the addition and the additive quantity. The addition of glass fiber exhibits higher properties than the other additive, and the modulus and yield stress increase with increasing additive amount (Guiqin Li et al., 2018). Mustafa et al. (2021) studied the tensile and Charpy impact behavior of an e-glass /unsaturated polyester laminated composite material at elevated temperatures. They found that the temperature affects the impact performance and the failure mechanism of the composite. The failure mechanism varied from fiber breakage and delamination at high temperature to matrix cracking at room temperature (Mustafa Baqir Hunain et al., 2021).

Chen et al. (2020) studied the effect of temperature on the mechanical properties and deformation mechanism of a high Mn steel with a composite structure. They found that the yield strength and elongation of the composite increased simultaneously as the tensile temperature decreased from room temperature (RT) to a low temperature (-180°C) (Xiaoman Chen et al., 2020). Noaman et al. (2023) studied the effect of pH on the mechanical properties of PVC/PVC sandwich plates reinforced with 0.95 wt.% glass fiber. The results showed that mechanical properties decreased with exposure time in acidic and alkaline media, whereas they remained stable in neutral conditions (Noaman et al., 2023). Ebrahiem et al. (2021) investigated fiber–adhesive composites to enhance the bond strength of PVC plates using different adhesives (epoxy, polyester, and polyvinyl acetate). The results indicated that reinforced PVC composites could serve as a cost-effective alternative to steel pipelines for high-pressure natural gas transport (Ebrahiem et al., 2021). Ebrahiem E et al. (2020) investigated the effect of adhesion type and adhesive thickness on the bond strength of PVC plastic plates reinforced with fiber–adhesive composites. The results showed that PVC/PVC sandwich plates achieved higher strength than single PVC plates, with improvements of 50% (epoxy), 65% (polyester), and 100% (polyvinyl acetate). Polyvinyl acetate provided the best overall performance (Ebrahiem E et al. 2020).

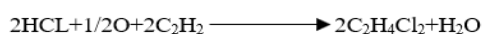
The main objective of this work is to study the mechanical properties (strength, energy to fracture, and adhesion shear) of PVC/PVC sandwich plate having glass fiber and different types of adhesives (epoxy, polyester, and polyvinyl chloride) at different temperatures, and also at strong alkaline & acidic media at different times (2,4 and 6 Hrs). The activation energy was studied, and it was found that PVC/PVC sandwich plates reinforced with glass fiber and blended with polyvinyl acetate have the highest activation energy compared with epoxy and polyester.

2. EXPERIMENTAL METHOD

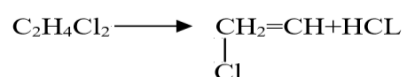
2.1. Material

2.1.1. Polyvinyl chloride

Polyvinyl chloride (PVC), prepared by the polymerization of the monomer vinyl chloride, is more commonly used today. Ethylene obtained from the cracking of naphtha, a process of breaking down higher molecular weight petroleum present into lower molecular weight products, is converted into ethylene dichloride by reacting it with chlorine in the liquid phase using an iron chloride catalyst at 30-50 °C.



Ethylene chloride is subsequently cracked into vinyl chloride.



Mechanical properties of PVC thermoplastic are shown in Table 1.

2.1.2. Adhesive

Three types of adhesive materials are used in this study and prepared with different thicknesses. These adhesives are epoxy, polyester and polyvinyl acetate. Testing specimens were prepared using a special press and a special stamp to control thickness, as shown in figures 1 and 2.

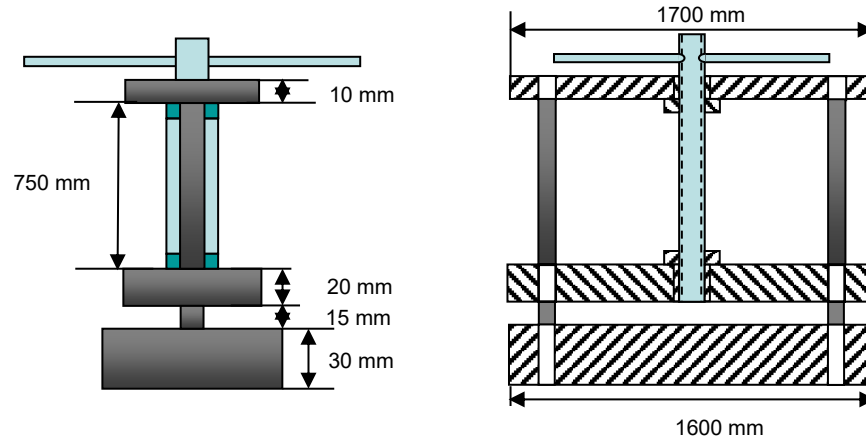


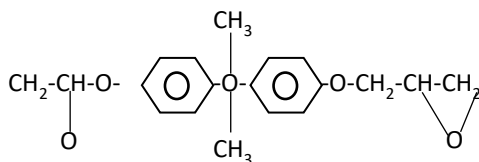
Figure 1: A Special Press for Controlling the Thickness of Adhesives



Figure 2: A Special Stamp for Controlling the Size of Adhesive

2.1.2.1 Epoxy Resin

Epoxy is characterized by the presence of the epoxy group a three-membered ring with two carbons and an oxygen, thus:-



Epoxy resin was obtained from C.M.B Company. It is a two-component, solvent-free, non-pigmented liquid epoxy resin

It is prepared by blending the hardener with resin at a ratio of 1:2. Epoxy resin is dry after 24 Hrs on the PVC samples. Between PVC/PVC, surface plates.

Epoxy resin is used as an adhesive between the PVC plates with different thicknesses (1, 1.5, 2, and 2.5 mm). The mechanical properties of epoxy resin are illustrated in Table 1.

2.1.2.2 Polyester

Polyester is formed by the condensation polymerization of a diacid with dialcohol (a diacid means two organic acid groups are present in a molecule and a dialcohol, sometimes called a diol, has two alcohol groups in the molecule). The acid group at one end of the diacid reacts with the alcohol group at one end of the diol to form a bond linking the two molecules, releasing water as a byproduct.

The linking group formed is called an ester; this step is called a condensation reaction. Polyester is prepared by blending the hardener with the resin at a 1:3 ratio; it will dry on the PVC samples after 24 Hrs.

Polyester is used as an adhesive between the PVC plates with different thicknesses (1, 1.5, 2 and 2.5 mm). The mechanical properties of polyester are illustrated in Table 1.

2.1.2.3. Polyvinyl Acetate

Crystalline polyvinyl acetate is used as an adhesive material in this study. It should be soluble in a solvent such as toluene by heating under indirect conditions, and then used as an adhesive on the PVC sample.

Polyvinyl acetate is used as an adhesive between the PVC plates of different thicknesses (1, 1.5, 2, and 2.5 mm). The mechanical properties of polyvinyl acetate are illustrated in Table 1.

Table Mechanical Properties of Polyvinyl Chloride and Different Resins

Material	σ_u (MPa)	E_g (N.m/m ³)	E (GPa)	H (BHN)	Impact (Nm)	Σu (%)
Polyvinyl Chloride	52	14	1.4	26	3.5	1.1
Epoxy	75.9	17	3.5	30	3	5.3
Polyester	77	3.4	20	30	4.5	8
Polyvinyl acetate	81.5	4.5	23	55	6	11.7

2.2. Reinforcement

2.2.1. Glass fiber

Glass fiber was used as a reinforcing material at different weight percentages (0.19 Wt.%, 0.38 Wt.%, 0.57 Wt.%, 0.76 Wt.%, and 0.95 Wt.%) and blended with different adhesives (epoxy, polyester, and polyvinyl acetate).

2.2.2. Glass textile

Glass textile is also used as a reinforced material. Only one layer of glass textile is used.

2.3. Testing

2.3.1. Tensile test

A universal testing machine was used to obtain a tensile load –displacement diagram. Special grips were prepared to hold the specimen and fix it to the machine during the test. The machine was first set up at a rate of 5 mm /min.

(In which the specimen is pulled apart in the test as indicated in ASTM specifications) (ASTM D 5083,2023 ,ASTM: D695-96,2023). Maximum load, maximum displacement, ultimate tensile strength, and maximum tensile strain were recorded along with load-displacement data. Figure 3 reveals the tensile test specimen used in the experimental work.

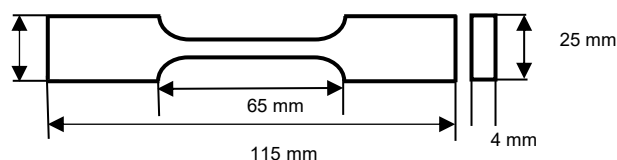


Figure 3: Tensile Test Specimen

These results are usually expressed in terms of stress and strain, which are independent of the specimen geometry. Engineering stress (σ) is defined as a ratio of the load on the specimen (P), to the original cross-sectional area (A_0)

$$\sigma = \frac{P}{A_0} \quad (1)$$

Engineering strain is defined as the ratio of the change in length of the specimen (ΔL), to the original length (L_0)

$$\epsilon = \frac{L - L_0}{L_0} = \frac{\Delta L}{L_0} \quad (2)$$

At the beginning of the test, the material extends elastically; this signifies that if the load is released, the specimen will return to its original length. The material is said to have passed its elastic limit when the load is sufficient to initiate plastic or non-recoverable. As a specimen is further elongated, the engineering stress increases, and the material is said to work harden or strain harden. The stress reaches a maximum at the ultimate strength. At this point, the specimen develops a neck: a local decrease in cross-sectional area where further deformation is concentrated. After necking begins, the engineering stress decreases with increasing strain until the specimen fractures.

2.3.2. Adhesion shear

This test is very important for determining the adhesion force between the specimen and the adhesive. The same universal testing machine was used to obtain the shearing load-displacement diagram. A special fixture was prepared to shear the specimen. The punch was moved downwards with a uniform rate of 1.5 mm/min. The specimen prescribed by ASTM is a plate with an 11 mm hole drilled through its center. Maximum shearing load and maximum shear strength were recorded along with load –displacement data. Figure 4 illustrates the adhesion shear specimen used in the experimental work.

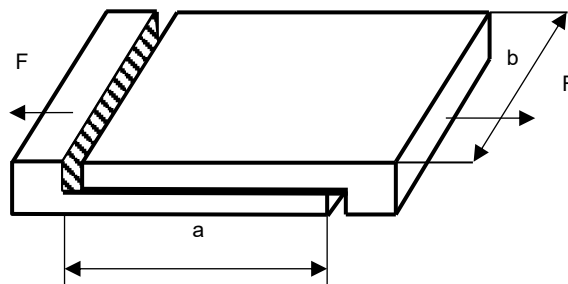


Figure 4: Adhesion Shear Specimen

The shear strength is calculated by dividing the maximum load by the area of the sheared edge by using the following equation

$$\zeta = \frac{F}{2ab} \quad (3)$$

Figure 5 displays the adhesion shear test device used in the experimental work



Figure 5: Adhesion Shear Test Device

2.3.3. Impact test

The Brooks pendulum impact tester was used to evaluate plastic materials using the Izod test, which measures the energy required to rupture a specimen of specific dimensions. This rupture was done by impacting a known energy value with a special striker mounted on a pendulum and measuring the kinetic energy absorbed by the impact. In its elevated position, the pendulum possesses a definite potential, which is converted to kinetic energy at its lowest swing. The pendulum achieves maximum kinetic energy at its lowest swing position, just before it meets the test specimen. The impact energy absorbed by the specimen during rupture is measured as the difference between the height of drop before rupture and the height of rise after rupture of the test specimen. It is read directly off the dial scale, which is calibrated in joules. Figure 5 reveals the adhesion shear test device, and Figure 6 illustrates the impact test device.



Figure 6: Impact Test Device

2.4. Water bath

The water bath is used to measure the thermal resistance of the reinforced thermoplastic specimens used in this test. The water bath consists of an electric heater, thermometer, and a temperature adjustment mechanism to maintain the water bath at the required temperature. The specimen was tested at different temperatures (35,45, 55, 65 and 75 °C) and at different times (2 , 4, and 6 Hrs). Figure 7 displays the water bath used in the experimental work of this study.



Figure 7: Water Bath Heater

3. RESULTS & DISCUSSIONS

3.1. Effect of Temperature on the Mechanical Behavior of PVC/PVC Sandwich Plates 0.95 Wt. % Glass Fiber with 2.5 mm Adhesive Thickness

3.1.1. Tensile Behavior

The effect of temperature at different times (2, 4, and 6 Hrs) on the stress- strain behavior of PVC/ PVC sandwich plates, 2.5 mm thickness, with different adhesives (epoxy, polyester, and polyvinyl acetate) blended with 0.95 Wt. % Glass fiber as a reinforcement is illustrated in Figures 8, 9, and 10.

As a result of increasing the temperature of PVC/PVC sandwich plates at different times, the mechanical behavior decreases compared with PVC/PVC sandwich plates and also it can be seen that the effect of temperature at different times on PVC/PVC sandwich plates having 2.5 mm of epoxy, polyester is higher than PVC/PVC sandwich plates polyvinyl acetate, this behavior is due to the different effect of temperature on the bond between glass fiber and adhesives.

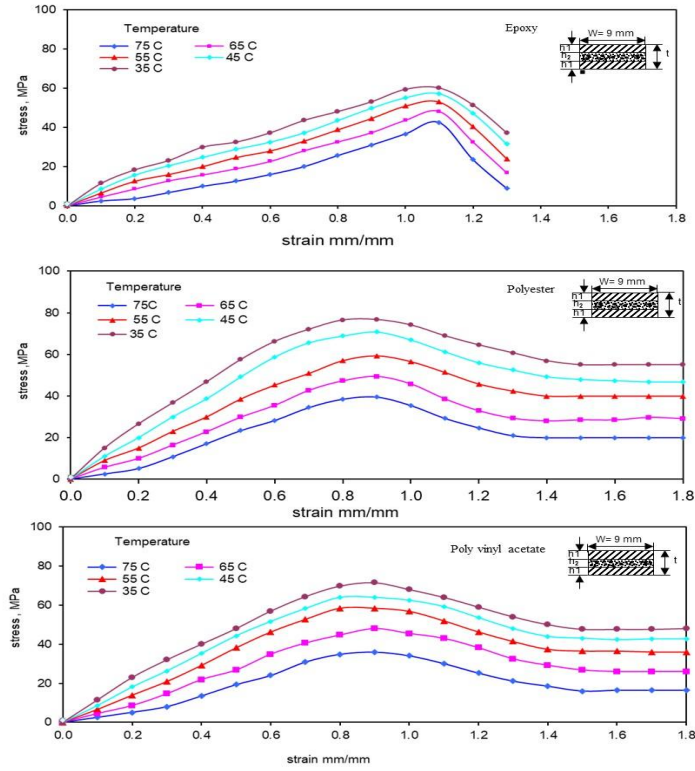


Figure 8: Effect of Temperature at 2 Hrs. on Stress/ Strain Diagram of PVC/PVC Sandwich Plates ($h_2 = 2.5$ mm, 0.95 Wt. % Glass Fiber)

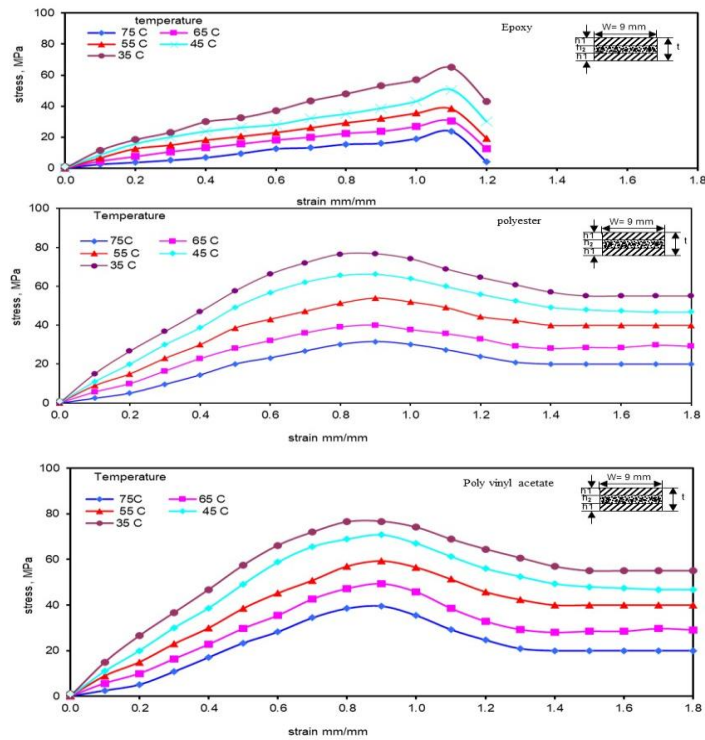


Figure 9: Effect of Temperature at 4 Hrs. on Stress/ Strain Diagram of PVC/PVC Sandwich Plate. ($h_2 = 2.5$ mm, 0.95 Wt. % Glass Fiber)

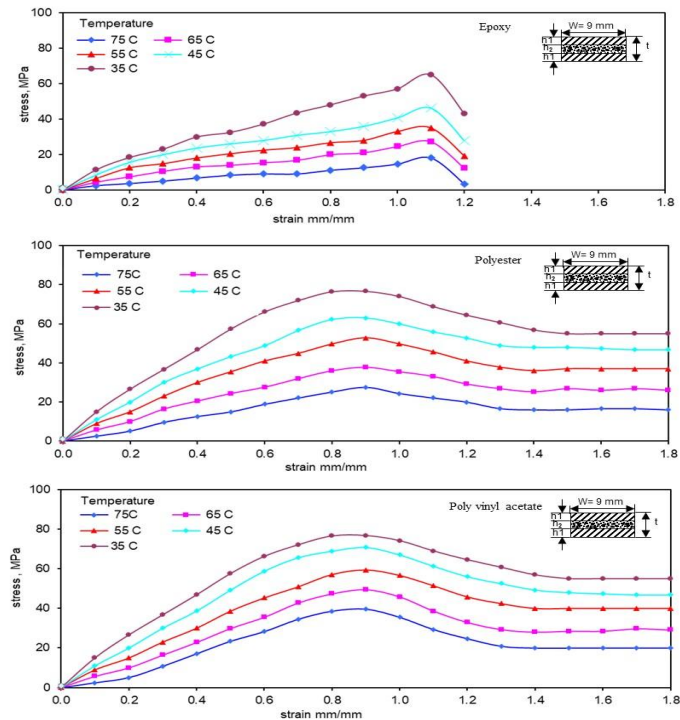


Figure 10: Effect of Temperature at 6 Hrs. on Stress/ Strain Diagram of PVC/PVC Sandwich Plates ($h_2 = 2.5$ mm, 0.95 Wt. % Glass Fiber)

3.1.2. Ultimate Strength

The effect of temperature at different times (2, 4 and 6 Hrs.) on the ultimate strength of PVC/ PVC sandwich plates 2.5 mm thickness different adhesives (epoxy, polyester and polyvinyl acetate) blended with 0.95 Wt. % glass fiber as a reinforcement is displayed in figures 11 a, 12 a and 13 a. The ultimate tensile strength of PVC/PVC sandwich plates decrease in order of increasing temperature at different times. The effect of increasing temperature at different times on PVC/PVC sandwich plates of polyester, epoxy is higher than polyvinyl acetate.

3.1.3. Modulus of Elasticity

The effect of increasing temperature at different times (2, 4 and 6 Hrs..) on the elastic modulus of PVC/ PVC sandwich plates 2.5 mm different adhesives (epoxy, polyester and polyvinyl acetate) blended with 0.95 weights percent glass fiber as a reinforcement is illustrated in figures (11 b, 12 b and 13 b).

It can be noticed that the Modulus of elasticity of PVC/PVC sandwich plates decrease with increasing the temperature at different times.

Energy to Fracture

The effect of increasing temperature at different times on the PVC / PVC sandwich plates 2.5 mm different adhesives (epoxy, polyester, and polyvinyl acetate) blended with 0.95 Wt. % glass fiber as a reinforcement is illustrated in figures (11 c, 12 c and 13 c). The energy to fracture decreases with increasing temperature at different times and with compared the three types of adhesives, the energy needed to fracture PVC/PVC sandwich plates having 2.5 mm thickness of polyvinyl acetate is higher than epoxy and polyester. In addition, it can be seen that the energy needed to fracture PVC/PVC sandwich plates 2.5 mm thickness adhesives is higher than PVC/PVC sandwich plates at different temperature at different times.

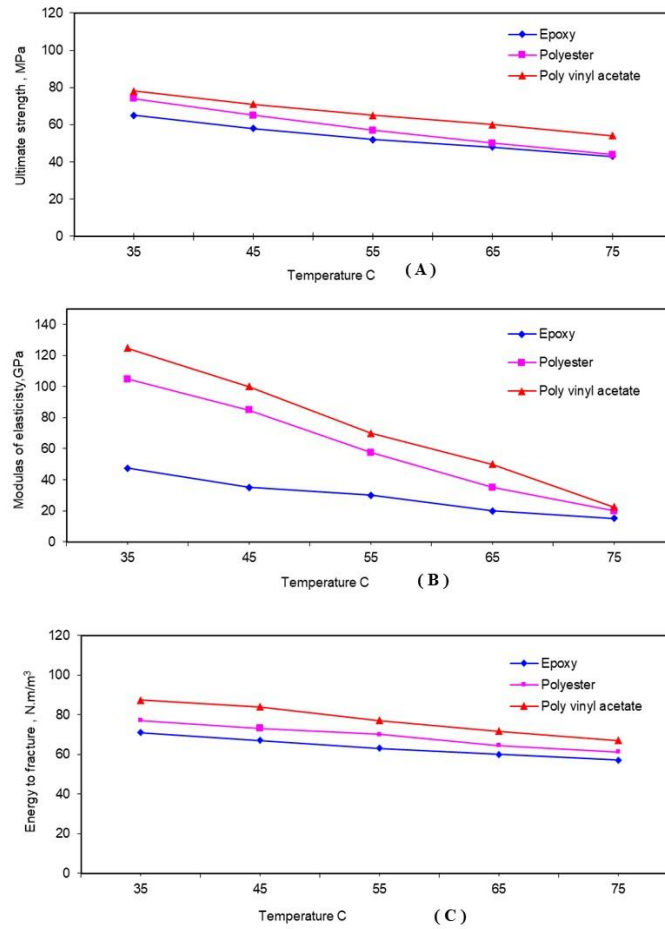


Figure 11: Ultimate Strength, Modulus of Elasticity and Energy to Fracture of PVC/PVC Plates Blended with 0.95 Wt. % Glass Fiber as a Function of Temperature Effect at 2 Hrs.

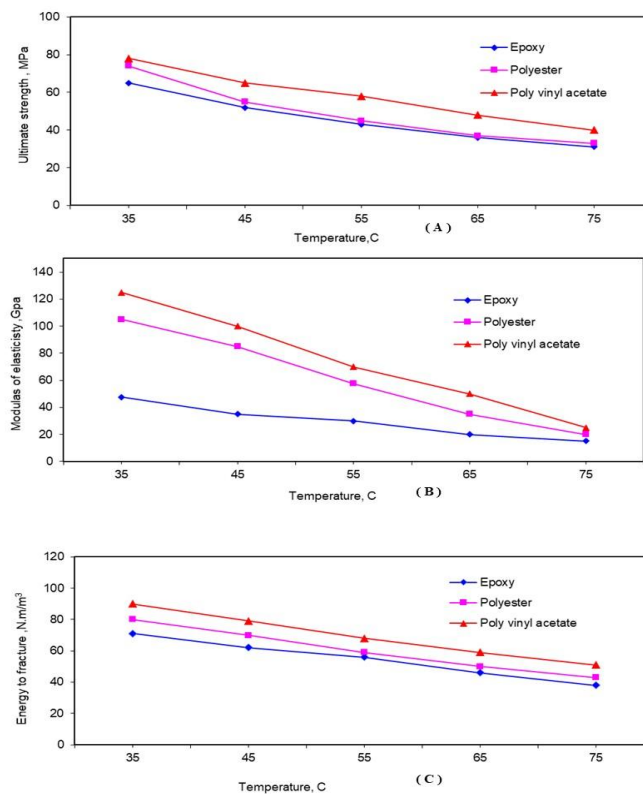


Figure 12: Ultimate Strength, Modulus of Elasticity and Energy to Fracture of PVC/PVC Sandwich Plates blended with 0.95 Wt. % Glass Fiber as a Function of Temperature Effect at 4 Hrs.

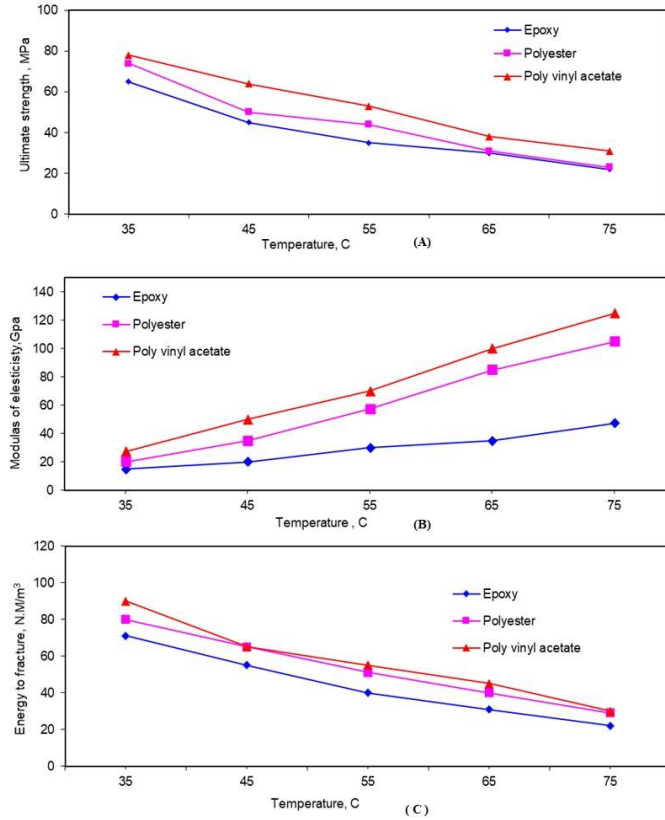


Figure 13: Ultimate Strength, Modulus of Elasticity and Energy to Fracture of PVC/PVC Sandwich Plates Blended with 0.95 Wt. % Glass Fiber as a Function of Temperature Effect at 6 Hrs.

3.1.4. Impact Energy

Figures 14, 15, and 16 reveal the effect of increasing temperature at different times (2, 4, and 6 Hrs) on the PVC/PVC sandwich plates, 2.5 mm thick, with three types of adhesives (epoxy, polyester, and polyvinyl acetate) blended at 0.95 Wt. % of glass fiber as a reinforcement. The energy absorbed for PVC/PVC sandwich plates having a 2.5 mm thickness of adhesive blended with 0.95 Wt. % as a reinforcement decreases with increasing temperature over time. It can be seen also that the energy absorbed of PVC/PVC sandwich plates having 2.5 mm polyvinyl acetate at different temperatures at different times is higher than polyester and epoxy resin.

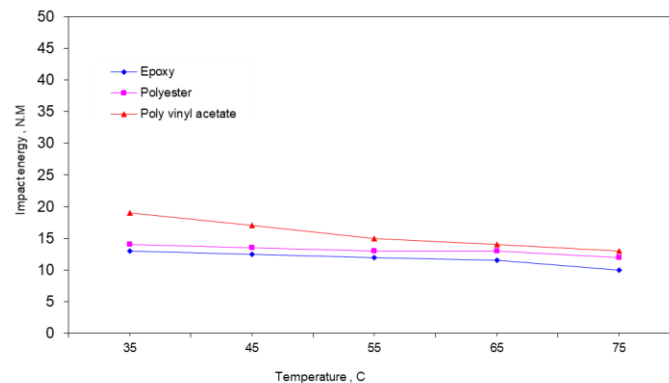


Figure 14: Effect of Temperature on Impact Energy of PVC/PVC Blended with 0.95 Wt.% Glass Fiber 2.5 mm at Different Adhesives and at 2 Hrs.

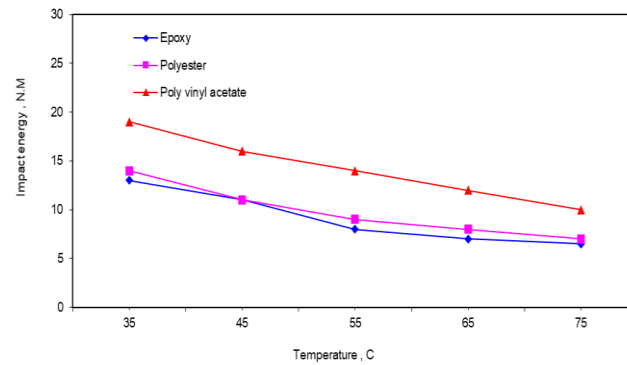


Figure 15: Effect of Temperature on Impact Energy of PVC/PVC Sandwich Plates Blended with 0.95 Wt.% Glass Fiber 2.5 mm at Different Adhesives and at 4 Hrs.

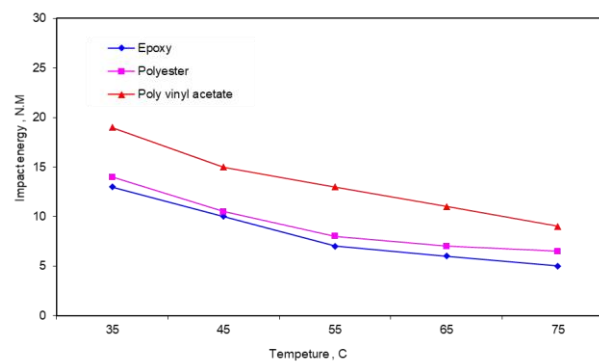


Figure 16: Effect of Temperature on Impact Energy of PVC/PVC Sandwich Plates Blended with 0.95 Wt.% Glass Fiber 2.5 mm at Different Adhesives and at 6 Hrs.

3.1.5. Adhesion Shear

Figures 17,18 and 19 reveal the effect of increasing temperature at different times (2, 4 and 6 Hrs.) on the PVC/PVC sandwich plates having 2.5 mm thickness of three types of adhesives (epoxy, polyester, polyvinyl acetate) blended with 0.95 Wt.% of glass fiber as a reinforcement. It can be seen that the value adhesion shear decreases with increasing temperature at different times with comparing the three types of adhesives it can be seen also that the adhesion shear of PVC/PVC sandwich plates having 2.5 mm polyvinyl acetate is higher than epoxy and polyester, this may explain the improvement of mechanical properties of PVC/PVC sandwich plates with 2.5 mm polyvinyl acetate blended with 0.95 Wt. % glass fiber compared with other adhesives.

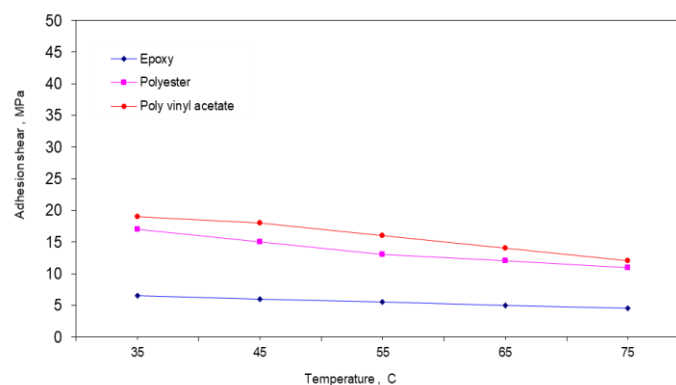


Figure 17: Effect of Temperature on Adhesion Shear of PVC/PVC Blended with 0.95 Wt.% Glass Fiber 2.5 mm at Different Adhesives and at 2 Hrs.

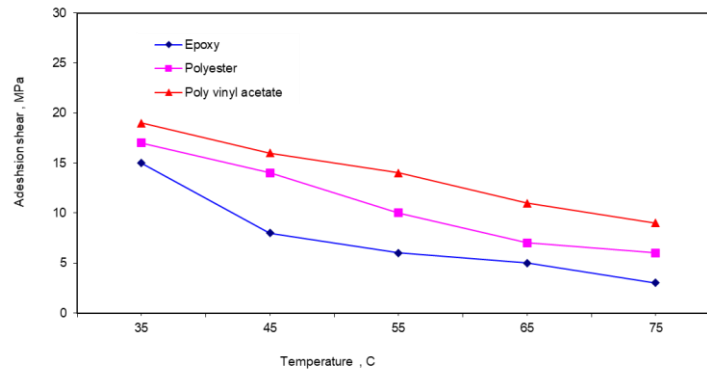


Figure 18: Effect of Temperature on Adhesion Shear of PVC/PVC Sandwich Plates Blended with 0.95 Wt.% Glass Fiber 2.5 mm at Different Adhesives and at 4 Hrs.

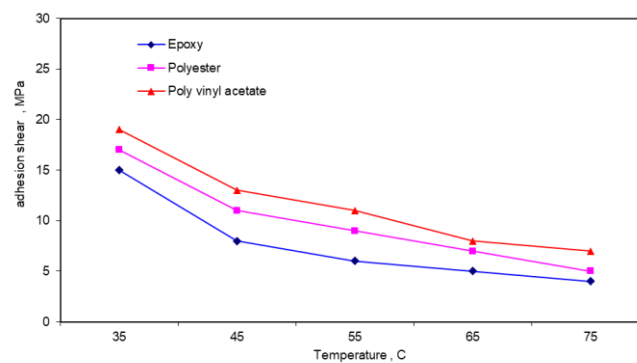


Figure 19: Effect of Temperature on Adhesion Shear of PVC/PVC Sandwich Plates Blended with 0.95 Wt.% Glass Fiber 2.5 mm at Different Adhesives and at 6 Hrs.

3.2. Composite Calculation

Modulus of elasticity of PVC/PVC sandwich plates having different Wt. % glass fiber blended with 2.5 mm thickness of adhesives (epoxy, polyester, polyvinyl acetate). A mathematical expression has been formulated for the dependence of the elastic modulus on the percentage of the constituent phases in a two-phase composite. The rule of mixture equations is as follows:

$$E_c = E_m V_m + E_f V_f \quad (4)$$

3.3. Elastic Modulus of PVC/PVC Sandwich Plates 2.5 mm Thickness of Adhesives Blended with Different Wt. % Glass Fiber at pH=7, Temp. = 35 °C

The effect of adding glass fiber content weight percent as a reinforced material at different time (2,4 and 6 Hrs.) on PVC/PVC sandwich plates having 2.5 mm thickness of three types of adhesives (epoxy, polyester and polyvinyl acetate) blended with different weight percent of glass fiber as a reinforced material at pH =7, temperature 35 °C are illustrated in figure 20, 21 and 22. It can be seen that the modulus of elasticity of the composite which are calculated from equations are increases with increasing the glass fiber content as a reinforced material and with increasing the time the modulus of elasticity of the composite decrease comparing the three types of adhesives which are on the same conditions It can be seen that the modulus of elasticity of the composite of PVC/PVC sandwich plates 2.5 mm thickness of polyvinyl acetate is the best compared with epoxy and polyester.

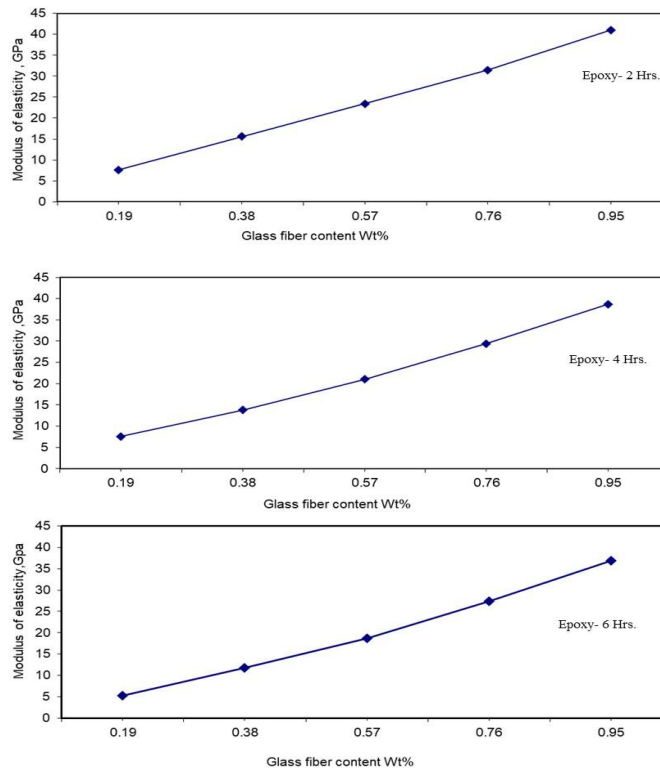


Figure 20: Effect of Glass Fiber Content by Wt. % at Different Times on Modulus of Elasticity of PVC/PVC Sandwich Plates 2.5 mm Thickness of Epoxy at pH = 7

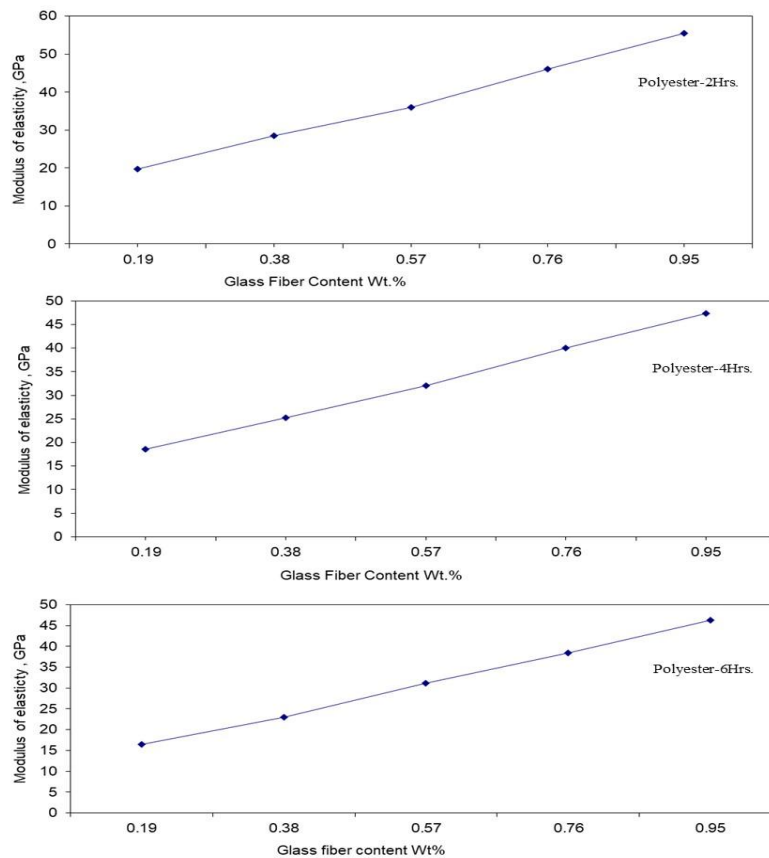


Figure 21: Effect of Glass Fiber Content by wt. % at Different Times on Modulus of Elasticity of PVC/PVC 2.5 mm Thickness of Polyester at pH = 7

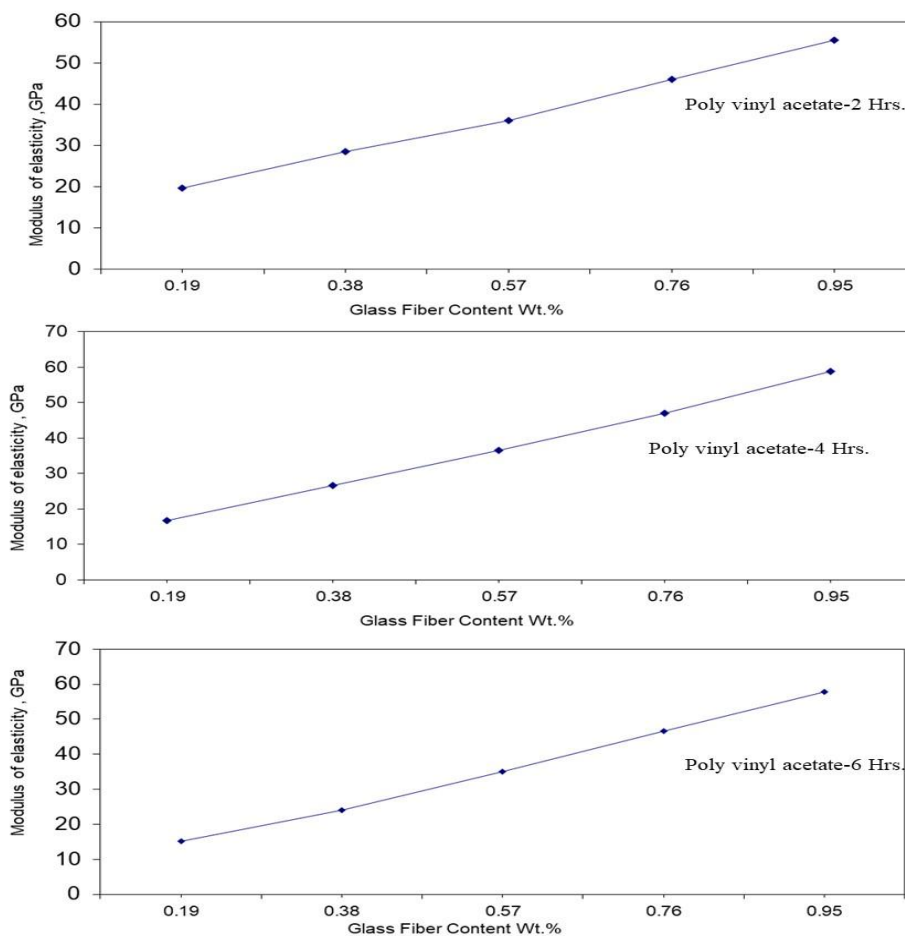


Figure 22: Effect of Glass Fiber Content by Wt. % at Different Times on Modulus of Elasticity of PVC/PVC 2.5 mm Thickness of Polyvinyl Acetate at pH = 7

3.4. Activation Energy of PVC/PVC Sandwich Plates 0.95 Wt. % Glass Fiber with 2.5 mm Adhesive at Different Temperatures and Times

Figure 23 a, b and c, which illustrate the ultimate tensile strength of PVC/PVC sandwich plates 2.5 mm thickness of adhesives (epoxy, polyester, and polyvinyl acetate) at different times (2,4 and Hrs) and different temperatures (35, 45,55,65 and 75 °C), from these figures, the slope of every curve is obtained.

Figure 24 displays the activation energy of PVC/PVC sandwich plates with a 2.5 mm thickness, using different adhesives (epoxy, polyester, and polyvinyl acetate) blended with 2.5 mm-thick glass fiber as the reinforcing material, at different times and temperatures. The activation energy is calculated using the Arrhenius equation as follows: -

$$E = E_0 \cdot e^{-Q/RT} \quad (5)$$

The activation energy of the polyvinyl acetate is the largest compared with the epoxy and polyester.

The highest activation energy of polyvinyl acetate can be explained due to this process is thermally activated. This due to the diffusion of molecules of polyvinyl acetate across the interface is higher than epoxy and polyester the mobility and solubility parameter can explain this effect.

This may explain the improvement of mechanical behavior of PVC/PVC sandwich plates with polyvinyl acetate compared with epoxy and polyester resin.

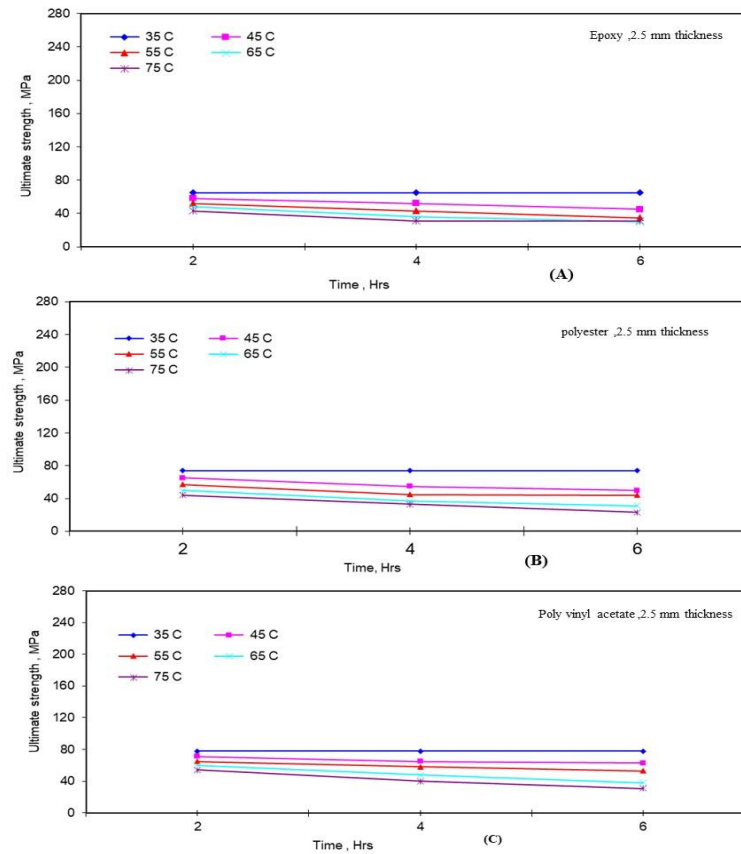


Figure 23: Effect of Temperature on Ultimate Strength of PVC/PVC 0.95 Wt. % Glass Fiber with 2.5 mm of Different Adhesives at Different Times and Temperatures

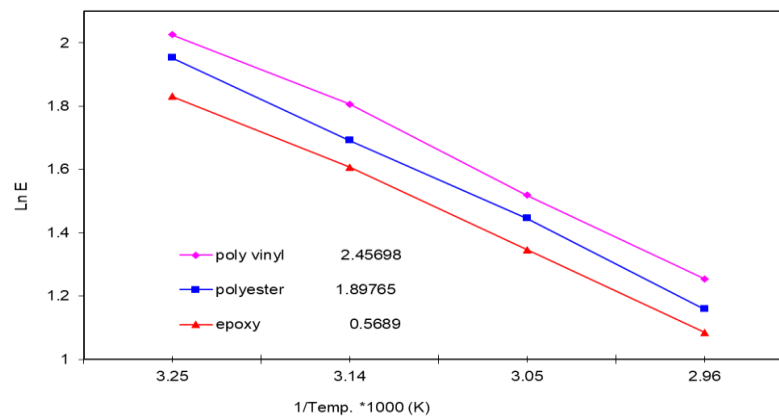


Figure 24: Arrhenius Plot of PVC/PVC 2.5 mm Thickness of Different Adhesives

4. Conclusions & Recommendations

As a result of increasing the temperature, the mechanical properties of the PVC/PVC sandwich plat affected as follows:

- Strength of PVC/PVC sandwich plates having glass fiber decreases depending on increasing temperature by 72% in the case of epoxy, in the case of polyester, and by 62%, 48% in the case of polyvinyl acetate.
- Energy to fracture of PVC/PVC sandwich plates having glass fiber blended with adhesive decreases with increasing temperature by 69% in the case of epoxy, 63% in the case of polyester, and 67 % in the case of polyvinyl acetate compared to the original case.
- Adhesion shear of PVC/PVC sandwich plates having glass fiber blended with adhesive decreases with increasing temperature, and the effect of increasing temperature on adhesion shear of polyvinyl acetate is lower than epoxy and polyester.

- The activation energy of PVC /PVC sandwich plates having glass fiber as a reinforced material blended with polyvinyl acetate is the largest compared with epoxy and polyester.

Nomenclature

Abbreviation	Description	Unit
A	Length of specimen	m
ASTM	American Society for Testing and Materials	
b	Width of specimen	m
d	Diffusion rate	m ² /S
E	Modulus of elasticity MPa	
F	Force	Kg
GRE	Glass reinforced epoxy	Kg/m ²
H	(BHN) Brinell hardness number	
L	Length	meter
M	Molecular weight	gram /g mole
Min.	minute	
mm	millimeter	
N.m	Newton meter	
PVC	Ploy Vinyl Chloride	
Q	Activation energy	K. Joule /mole
R	Gas constant	Pa. m ³ /K
t	Thickness	m
T	Temperature	K
W	Width	m
A ₀	Original area	m ²
E _c	Modulus of elasticity of composite	MPa
E _g	Energy to fracture	N.M/m ³
E _F	Modulus of elasticity of fiber	MPa
E _m	Modulus of elasticity of matrix	MPa
E ₀	Preexponentinl	m ² /S
VF	Volume of Fiber	m ³
V _m	Volume of matrix	m ³
σ _u	Ultimate strength	MPa
ε	Strain mm/mm	
ζ	Adhesion shear	MPa
Δε	Diff. in strain	mm/mm
ΔL	change in length	m
Σ _u	Sigma ultimate strength	MPa

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The Author conducted the experimental work, analyzed the data, and wrote the paper. No one else contributed in this work

Conflicts of interest

There are no conflicts to declare.

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The author will be responsible for their financial interest

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