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

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Abstract

Composites have been found to be the most promising and discerning material available in this century. Fiber-reinforced plastic is a composite material wherein a polymer is reinforced with fibers to enhance or add properties. These fibers are typically glass or carbon, although aramid, basalt, and even wood and paper have been used. Fiber reinforced plastics are commonly used in aerospace, automotive, marine, and construction industries because of their corrosion resistance and low weight-to-strength ratio.

In this work, the effect of acidic , alkaline and neutral mediums on the PVC / PVC sandwich plates with 0.95 Wt. % glass fiber blended with different types of adhesive materials (epoxy, polyester and poly vinyl acetate) were studied deeply. Different pH values (3, 5, 7, 9 and 11) as well as three time of exposure (2 hrs., 4 hrs. and 6 hrs.) were adopted. The mechanical properties of the PVC / PVC sandwich plates with glass fiber blended with different types of adhesive materials such as tensile strength, ultimate strength, modulus of elasticity, energy to fracture, impact energy and adhesion shear at different pH values were studied.

It has been found that the mechanical properties of PVC / PVC sandwich plates with 0.95 Wt. % glass fiber blended with different types of adhesives decrease with increasing the time in both strong alkaline medium, acidic medium and is constant in neutral medium.

Keyword: *Tensile Strength, Energy , fracture , pH, adhesive.*

1. Introduction

Weight saving is one of the main reasons for using composite materials rather than conventional materials for components. While composites are lighter, they can also be stronger than other materials, for example, reinforced carbon-fiber can be up to five times stronger than 1020 grade steel and only one fifth of the weight, making it perfect for structural purposes [1,2]. Another advantage of using a composite over a conventional type of material is the thermal and chemical resistance as well as the electrical insulation properties [3]. Unlike conventional materials, composites can have multiple properties not often found in a single material [4,5]. The aircraft engineers are increasing searching for the materials that have many advantages regarding densities, strength, stiff, abrasion ,impact resistance and resist corrosion [6].

A composite material is a combination of two materials with different physical and chemical properties [7]. When they are combined, they create a material that is specialized to do a certain

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job, for instance, to become stronger, lighter, or resistant to electricity [8]. They can also improve strength and stiffness. The reason for their use over traditional materials is because they improve the properties of their base materials and are applicable in many situations [9].

Composites have permeated our everyday lives: They are used in the cars we drive, golf clubs we swing, pipes that remove wastewater from our neighborhoods, and much more. Some applications, such as rocket ships, probably wouldn’t get off the ground without composite materials [10,11].

Composites offer many benefits. Key among them is strength, lightweight, corrosion resistance, design flexibility, and durability [12]. There are many types of composite materials such as carbon-reinforced fiber plastic, glass fiber reinforced aluminum, composites with carbon nanotubes, and many more. Other types of composite include metal-matrix and ceramic-matrix composites[13]. The enhanced mechanical properties of the composite are due to suing special materials i.e., glass, carbon, and aramid fibers,-------etc. [14]. Composite materials are classified according to their matrix compound. But their reinforcing phase can be metals, polymers, or ceramics again. Bur composites are defined according to their matrix compound [15,16].

Mohamed et al.,[17] studied the effects of fiber size and fiber content on mechanical and physical properties of Mengkuang reinforced thermoplastic natural rubber composites. They found that the maximum tensile strength and tensile modulus were obtained at 20% fiber content of 250 µm fiber size. Impact strength gradually decreased with the increased percentage of fiber content at fiber size, 125 µm and 250 µm. The highest tensile strain at break and lowest water absorption was observed at 10% fiber content for all sizes being studied.

K Yang et al., [18] studied the influence of resin content on the mechanical properties of composite laminates. The test results show that the tensile strength of the carbon fiber composite laminates increases first and then decreases with the change of resin content. When the resin content is 35%, the tensile strength reaches the maximum

P Skalková et al., [19] studied the properties of epoxy composite materials reinforced with glass, carbon and aramid fibers. The composites were made by hand lay-up and vacuum infusion process with 8, 10, 12 number of fabric layers.

The main purpose of this paper is to study the mechanical properties of the PVC / PVC sandwich plates with glass fiber and different types of adhesive materials such as epoxy, polyester and poly vinyl acetate in alkaline , acidic and neutral medium at different time (2 hrs. ,4 hrs. and 6 hrs.).

2. Experimental Method

2.1 Material

2.1.1. Poly Vinyl Chloride Material (PVC)

The poly Vinyl chloride material is currently manufactured by the polymerization of the monomer. Vinyl chloride and ethylene are the most used materials now adays. Ethylene is obtained from the breaking down higher molecular weight petroleum fraction into a lower molecular weight product then it's converted into ethylene dichloride by a chemical reaction with chlorine using an iron chloride as a catalyst at 30-50 ^oC.

$$2HCL+1/2O+2C_2H_2 \rightarrow 2C_2H_4Cl_2+H_2O$$

Ethylene chloride is subsequently cracked into vinyl chloride material

$$C_2H_4Cl_2 \longrightarrow \underset{\textstyle Cl}{\overset{}{CH_2}}{=}CH+HCL$$

The mechanical properties of poly vinyl chloride material is shown in table 1.

2.1.2. Adhesive

The adhesive materials with different thicknesses were used in this study were epoxy, polyester and poly vinyl acetate. These adhesive materials were prepared by using a special device and a special stamp to control the thickness of the adhesive materials as shown in figures 1 and 2

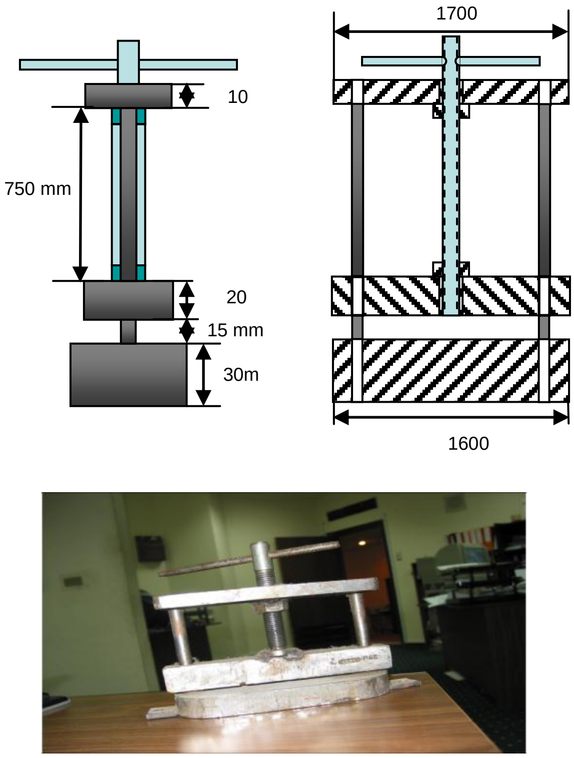
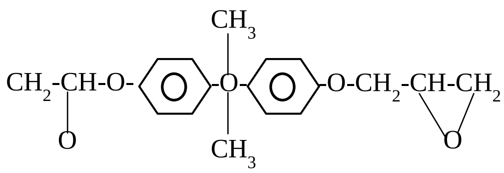


Figure 1: A special Device for Controlling the Thickness of the Adhesive Material

Figure 2: A Special Stamp for Controlling the Thickness of the Adhesive Material

2.1.2.1 Epoxy Adhesive Material

The epoxy adhesive material is known by the presence of epoxy group in three rings with two carbons and an oxygen according to the following composition



The epoxy adhesive material was brought from the Chemicals for Modern Building Company and it consists of two main components, these components are solvent free and non-pigmented liquid. It is prepared by mixing the hardener with resin at ratio of 1:2, The epoxy adhesive material will dry after 24 hrs. on the PVC sandwich plates

The epoxy adhesive material was used as an adhesive between the PVC sandwich plates at different thicknesses (1mm, 1.5 mm, 2 mm and 2.5 mm).

The mechanical properties of the epoxy adhesive material are shown in table 1

2.1.2.2 Polyester Adhesive Material

The polyester adhesive material is prepared by the polymerization of a diacid with dialchol. The acid group in one end of the diacid reacts with the alcohol group in one end of the diol to make a chemical bond between the two molecules and split out water as a byproduct. The group which was formed called an ester, this reaction is called condensation reaction. The polyester adhesive material is formed by blending the hardener with resin with ratio of 1:3 then the mixture will dry after 24 hrs. on the PVC sandwich plates.

The polyester adhesive material was used as an adhesive between the PVC sandwich plates at different thicknesses (1mm, 1.5mm, 2 mm and 2.5 mm).

The mechanical properties of the polyester adhesive material are displayed in table 1.

2.1.2.3 Poly Vinyl Acetate Adhesive Material

The poly vinyl acetate adhesive material used in this study must be soluble in a solvent i.e., toluene by heating then used as adhesive on the PVC sandwich plate.

The poly vinyl acetate adhesive material was used as an adhesive between the PVC plates at different thicknesses (1 mm, 1.5 mm, 2 mm and 2.5 mm).

The mechanical properties of the poly vinyl acetate adhesive material are revealed in table 1.

Table: 1 Mechanical Properties of Poly Vinyl Chloride and Different Resins

Material	σu(MPa)	Eg (N.m/m^3)	E (GPa)	H (BHN)	Impact (N.m)	Σu (%)
Poly vinyl 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
Poly vinyl acetate	81.5	4.5	23	55	6	11.7

2.2. Reinforcement Materials

2.2.1 Glass Fiber Reinforced Material

Glass fiber was used in this work as a reinforced material with different weight percent (0.19 Wt. %, 0.38 Wt. %, 0.57 Wt. %, 0.76 Wt. % and 0.95 Wt. %). The glass fiber reinforced material was blended with different adhesive materials (epoxy, polyester and poly vinyl acetate) during the experimental work.

2.2.2 Glass Textile Reinforced Material

Glass textile also was used as a reinforced material. Only one layer from glass textile was used in the test.

2.3 Testing

2.3.1. Tensile Mechanical Test Method

A new testing device was used to test the tensile diagram. Special grips were used to fix the specimen to the machine during the tensile test. The machine was adapted at rate 5 mm /minute. The PVC specimen was tested as per ASTM international standards and procedures [20,21]. The maximum load, maximum displacement, tensile strength and tensile strain were studied. Figure 3 shows tensile test specimen used in this study.

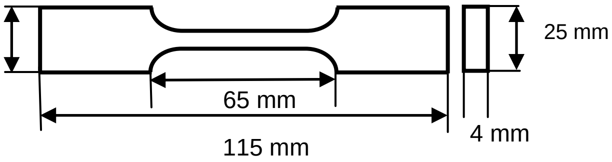


Figure 3: PVC Specimen for the Tensile Test Applications

The obtained results from the tensile test done are usually restarted regarding the stress and strain, they are independent of the geometry of the PVC specimen. The stress expression (σ) is defined as the ratio of the load on the PVC specimen (P) to the cross-sectional area (Ao) of the PVC specimen. The following equation reveals the stress

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

The strain (Є)is defined as the ratio of change in length of the PVC specimen (ΔL), to the length of the PVC specimen (Lo) according to the following equations

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

It should be noticed that the PVC specimen will extend elastically at the beginning of the tensile test; this can be observed when the load is released then the PVC specimen will return to its original length. The PVC specimen will passe to its elastic limit when the load is sufficient to initiate plastic or non-recoverable. When the PVC specimen is elongate then the stress will increase and the PVC specimen is strain harden. The stress of the PVC specimen will reach to the maximum at the ultimate strength. At the point, the PVC specimen will develop a neck: this is a local decrease in cross sectional area of the PVC specimen at which further deformation is noticed. After necking has begun, the stress of the PVC specimen will decrease with the strain until the specimen fractures.

2.3.2. Adhesion Shear Mechanical Test Method

The adhesion shear mechanical test method is essential to calculate the adhesion force between the PVC specimen and adhesive materials. The same testing device was used to record the shearing load-displacement diagram. Special fixture was prepared to shear the PVC specimen. The punch was moved downwards with a uniform rate of 1.5 mm / minute. The PVC specimen prescribed as per ASTM international standards and procedures is a plate with 11 mm hole drilled through the center of the PVC specimen. The maximum shearing load and maximum shearing strength were noticed along with load – displacement data. Figure 4 reveals the adhesion shear specimen used.

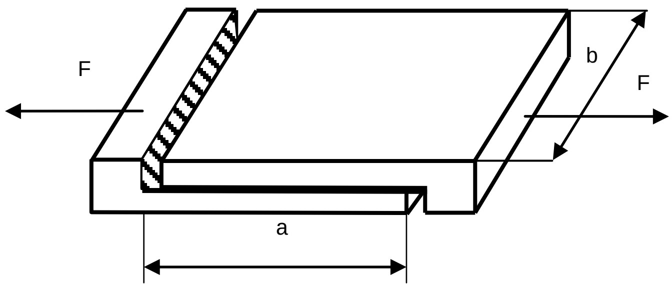


Figure 4 : Specimens used for the Adhesion Shear Test Method

The following equation was used to calculate the shear strength of the PVC specimen by dividing the maximum load by the area of the sheared edge

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

Figure 5 illustrate the adhesion shear test device used.

Figure 5: Adhesion Shear Test Device

2.3.3. Impact Mechanical Test Method

The pendulum impact tester device was used in this study to evaluate the plastic materials by Izod test which detriment the energy required for the fracture of the PVC specimen. This fracture was conducted by using a known value with a special striker mounted on the pendulum impact tester and measure the kinetic energy absorbed. In the elevated position, the pendulum possesses a definite potential which is translated to kinetic energy at its lowest swing. The pendulum impact tester does the maximum kinetic energy at its lowest swing position before it meets the test PVC specimen. The impact energy absorbed by the PVC specimen during the rupture is noticed as the difference between the height of drop before fracture and the height of rise after fracture of the PVC specimen. It is observed directly off the dial scale. Figure 6 illustrates the impact test device used in this study

Figure 6: Impact Test Device

2.4. pH Meter Test Method

The pH meter test is used to study the effect of acid, alkaline and neutral medium on the reinforced thermoplastic, the used values of pH are 3, 5 7, 9 and 11.

First, the acid or alkaline or neutral medium should be prepared by using strong acid like sulphuric acid and strong alkaline like sodium hydroxide. The strong acid or alkaline mixed with distillated water in a bottle until reach to the required concentration. The prop of pH meter is immersed in the solution to measure the required pH. Figure 7 displays the pH meter used.

Figure 7: pH Meter

3. Results & Discussions

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

3.1.1 Tensile Behavior

The effect of pH value at different time (2 hrs., 4 hrs. and 6 hrs.) on the stress / strain behavior of the PVC / PVC sandwich plates with 2.5 mm thickness from different adhesives (epoxy, polyester and poly vinyl acetate) blended with 0.95 Wt. % glass fiber as a reinforcement are illustrated in figure 8,9 and 10.

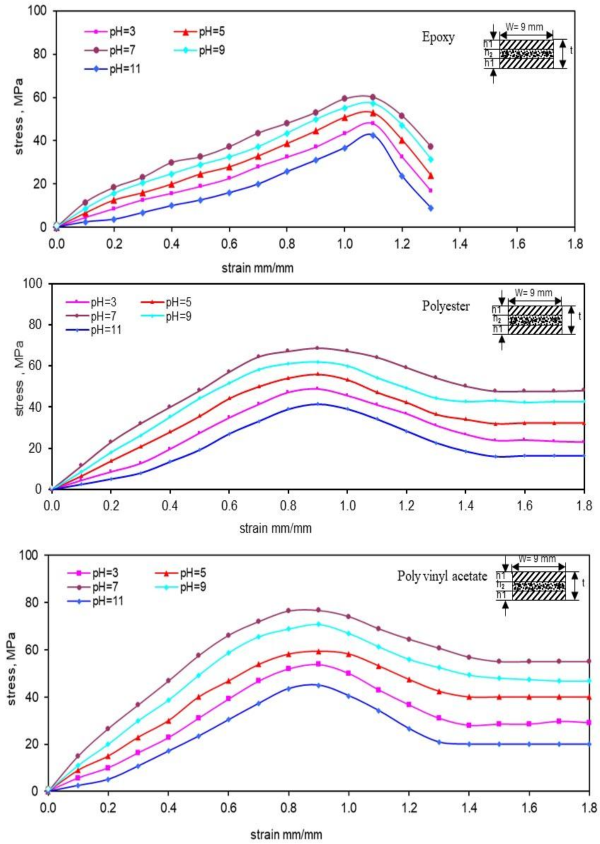


Figure 8: Effect of pH Values at 2 hrs. on the Stress /Strain Diagram of PVC/PVC Sandwich Plates (h_2= 2.5 mm, 0.95 Wt. % Glass Fiber)

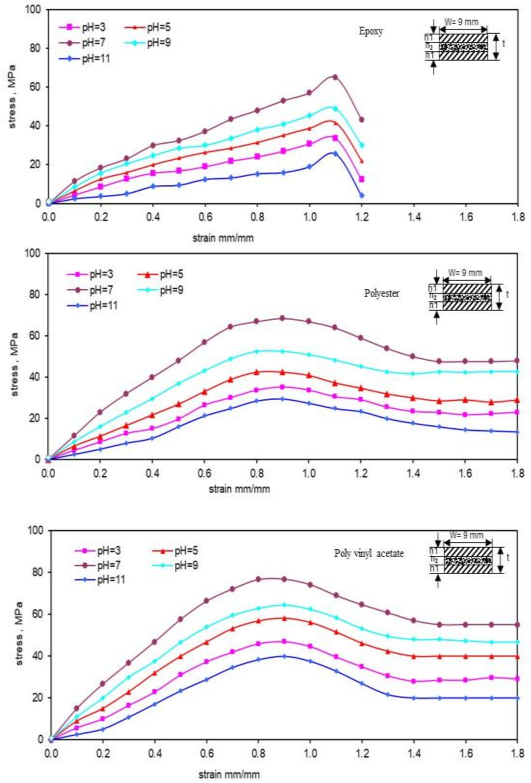


Figure 9: Effect of pH Values at 4 hrs. on Stress/ Strain Diagram of PVC / PVC Sandwich plates (h_2 = 2.5 mm, 0.95 Wt. % Glass Fiber)

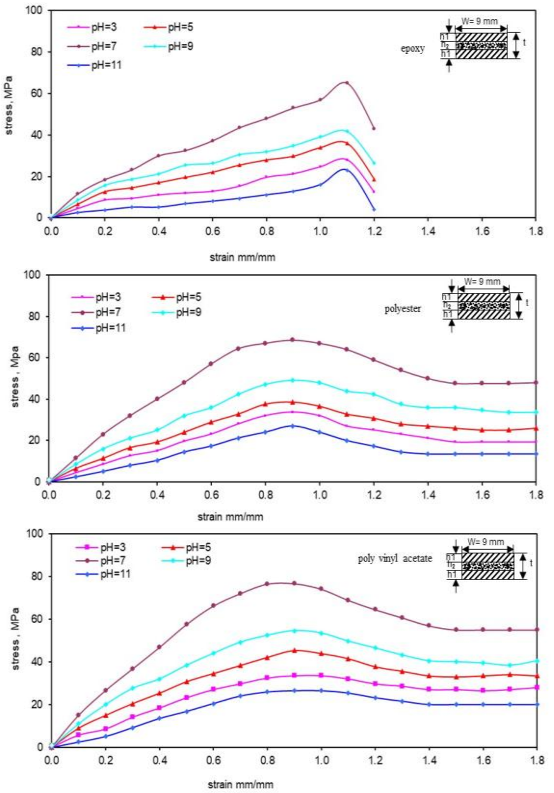


Figure 10: Effect of pH Values at 6 hrs. on the Stress /Strain Shape of PVC / PVC Sandwich Plate. (h_2 = 2.5 mm , 0.95 Wt. % glass fiber)

As a result of different pH values at different time (2 hrs. ,4 hrs. and 6 hrs.), the mechanical behavior decreases compared to PVC / PVC sandwich plates and also it can be observed that the effect of different pH values at different time on PVC / PVC sandwich plates with 2.5 mm of epoxy, polyester is higher than PVC / PVC sandwich plates with poly vinyl acetate, this behavior is due to the aggressive effect of the solution on the bond between glass fiber and adhesives.

3.1.2. Ultimate Strength with pH Values Effect at Different Time (2,4,6 hrs.)

Effect of different pH values at different time (2 hrs. ,4 hrs. and 6 hrs.) on the ultimate tensile strength test of PVC / PVC specimen with 2.5 mm from adhesive materials (epoxy, polyester and poly vinyl acetate) with 0.95 Wt. % glass fiber as a reinforcement is illustrated in figures 11 a, 12 a and 13 a. The ultimate tensile strength test of the PVC / PVC sandwich plates decreases with pH values at different time. The effect of pH values at different time on PVC / PVC sandwich plates of polyester, epoxy is higher than poly vinyl acetate.

3.1.3. Modulus of Elasticity with pH Values Effect at Different Time (2,4,6 hrs.)

The effect of different pH values at different time (2 hrs., 4 hrs. and 6 hrs.) on the elastic modulus test of the PVC / PVC specimen with 2.5 mm from adhesive materials (epoxy, polyester and poly vinyl acetate) with 0.95 Wt. % glass fiber as a reinforced material at different time is illustrated figures 11 b, 12 b and 13 b. It can be concluded that the modulus of elasticity of the PVC / PVC specimen decreases with increasing the pH value at different time.

3.1.4. Energy to Fracture Test with pH Values Effect at Different Time (2,4,6 hrs.)

The effect of different pH values at different time (2 hrs., 4 hrs. and 6 hrs.) on the PVC / PVC sandwich plates with 2.5 mm different adhesives (epoxy, polyester, and poly vinyl acetate) blended with 0.95 Wt. % glass fiber as a reinforcement at different time are illustrated in figure 11 c, 12 c and 13 c. It can be noticed that the energy to fracture test decreases with increasing the pH values at different time compared to the three types of adhesives, the energy required for the rupture of the PVC / PVC specimen with 2.5 mm thickness of poly vinyl acetate is greater than epoxy and polyester adhesive materials. In addition, the energy required for the fracture of PVC / PVC sandwich plates with 2.5 mm thickness of adhesives is higher than PVC/PVC sandwich plates with pH different values at different time.

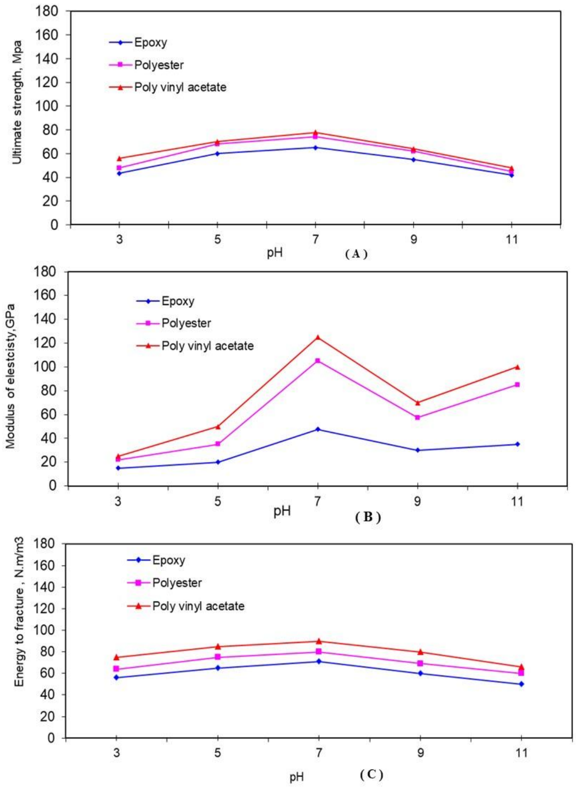


Figure 11: Ultimate Strength, Modulus of Elasticity and Energy to Fracture Mechanical Tests for the PVC / PVC Sandwich Plates with 0.95 Wt.% Glass Fiber and 2.5 mm from Different Adhesives Thicknesses as a Function of pH Effect at 2 hrs.

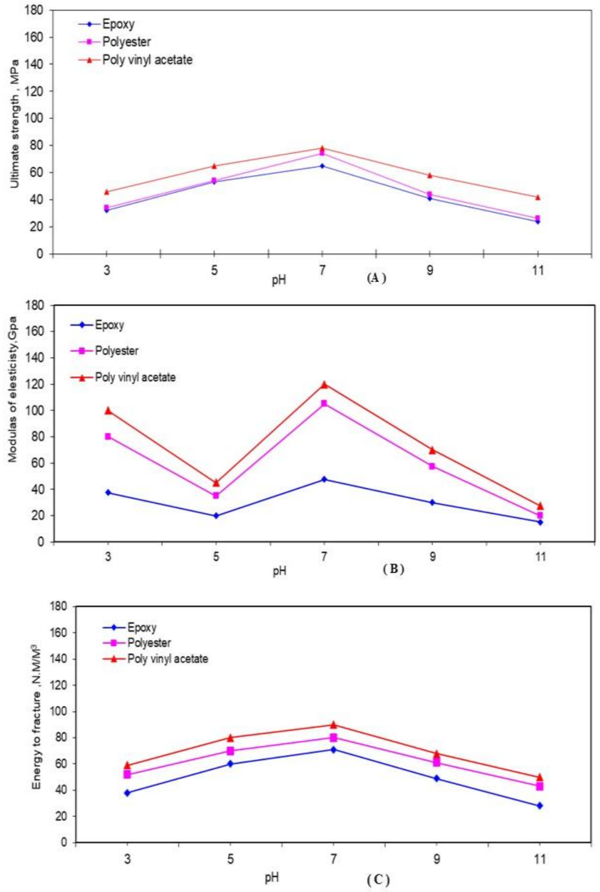


Figure 12: Ultimate strength, Modulus of Elasticity and Energy to Fracture of PVC / PVC Sandwich Plates with 0.95 Wt.% Glass Fiber and 2.5 mm from Different Adhesives Thicknesses as a Function of pH Values at 4 hrs.

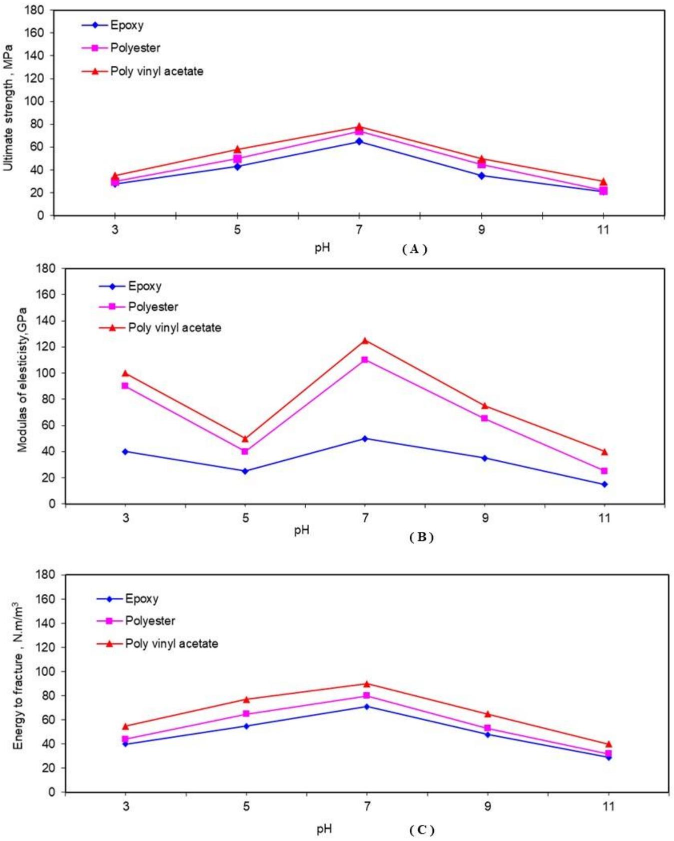


Figure 13: Ultimate Strength, Modulus of Elasticity and Energy to Fracture Mechanical Tests for the PVC/PVC Plates Blended With 0.95 Wt.% glass fiber as a function of pH Values at 6 hrs.

3.1.5. Effect of pH Values on the Impact Energy at Different Time (2,4,6 hrs.)

Figures 14, 15 and 16 reveal the effect of pH with different values at different time (2 hrs., 4 hrs. and 6 hrs.) on the energy absorbed of PVC / PVC specimen with 2.5 mm thickness from different adhesive materials (epoxy, polyester and poly vinyl acetate) mixed with 0.95 Wt. % as a reinforced material. The test revealed that the energy absorbed by the PVC / PVC specimen decreased when different values of pH at different time specially in the acid and alkaline medium were used .The energy absorbed by the PVC / PVC specimen with 2.5 mm poly vinyl acetate at different pH values and different time is greater than polyester and epoxy adhesive materials.

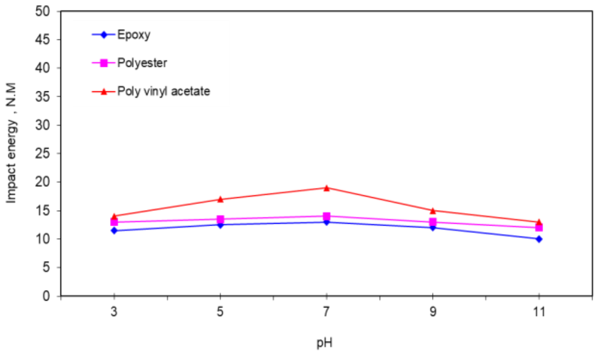


Figure 14: pH Values Effect on the Impact Energy Test of PVC/PVC Sandwich Plates with 0.95 Wt.% Glass Fiber and 2.5 mm from Different Adhesives Thicknesses at 2 hrs.

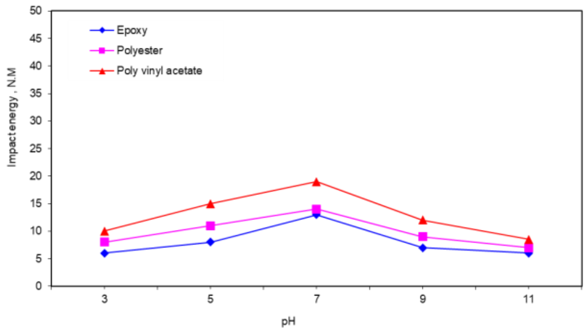


Figure 15: Effect of pH Values on Impact Energy of the PVC/PVC Sandwich Plates with 0.95 Wt.% Glass Fiber and 2.5 mm from Different Adhesives Thicknesses at 4 hrs.

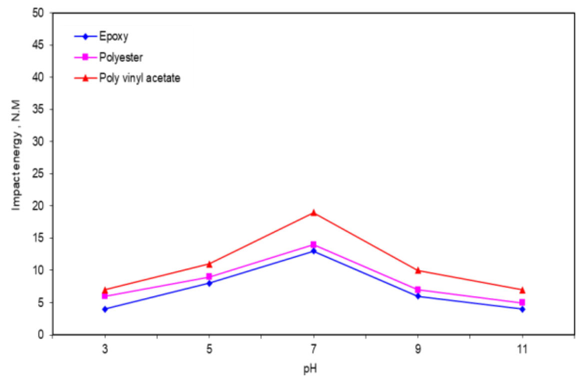


Figure 16: Effect of pH Values on the Impact Energy of PVC/PVC with 0.95 Wt.% Glass Fiber and 2.5 mm from Different Adhesives Thicknesses at 6 hrs.

3.1.6. Effect of pH Values on Adhesion Shear at Different Time

The effect of pH value at different time (2 hrs., 4 hrs. and 6 hrs.) on the adhesion shear of the PVC/ PVC specimen with 2.5 mm different adhesives (epoxy, polyester, and poly vinyl acetate) blended with 0.95 Wt. % glass fiber as a reinforcement at different time is illustrated in figures 17, 18 and 19. It can be seen that the value of adhesion shear decreases when pH at different values are used at different time, with comparing the three types of adhesives. The adhesion shear of PVC / PVC specimen with 2.5 mm poly vinyl acetate is greater than epoxy and polyester adhesive materials. This shows the improvement of mechanical properties of the PVC / PVC specimen with 2.5 mm poly vinyl acetate adhesive material mixed with 0.95 Wt. % of glass fiber compared to other adhesive materials.

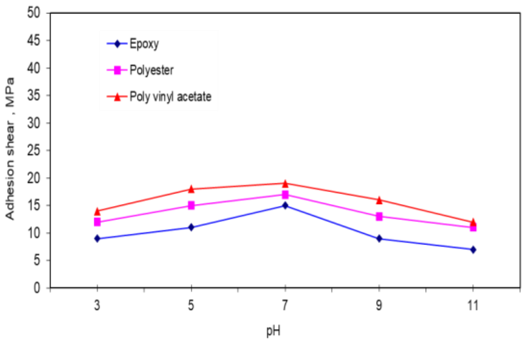


Figure 17: Effect of pH Values on Adhesion Shear of PVC / PVC Sandwich Plates with 0.95 Wt.% Glass Fiber and 2.5 mm from Different Adhesives Thicknesses at 2 hrs.

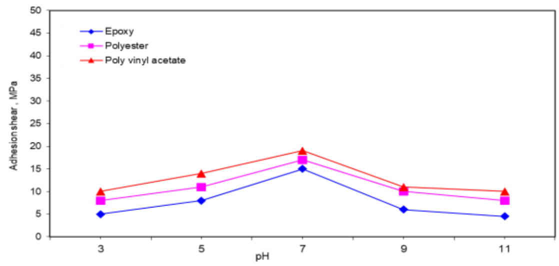


Figure 18: Effect of pH Values on Adhesion Shear of PVC/PVC Sandwich Plates with 0.95 Wt.% Glass Fiber and 2.5 mm at Different Adhesives Thickness at 4 hrs.

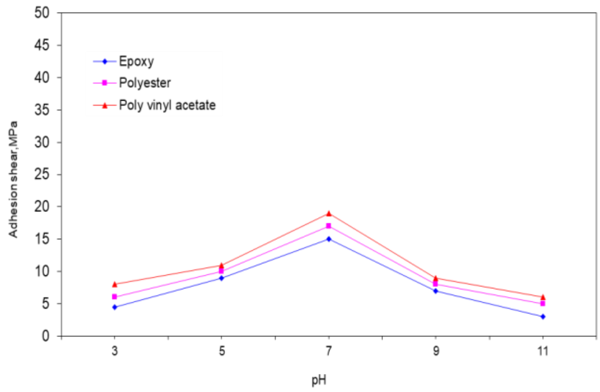


Figure 19: Effect of pH Values on the Sheer Force of PVC/PVC with 0.95 Wt.% glass fiber and 2.5 mm Different Adhesives Thickness at 6 hrs.

4. Conclusions & Recommendations

The mechanical properties of the PVC / PVC sandwich plates with 0.95 Wt. % glass fiber blended with adhesive materials decrease with increasing the time in both strong alkaline medium, acidic medium and is constant in neutral medium (at pH=7). These mechanical properties include the following: -

- The strength of PVC / PVC sandwich plates with glass fiber decreases depending on adding a strong alkaline or acidic medium by 60 % in strong acid and 62 % in strong alkaline medium when epoxy adhesive material was used as an adhesive, in case of polyester adhesive the strength decreased by 56 % in strong acid and 59 % in strong alkaline medium .in case of poly vinyl acetate adhesive the strength decreased by 45 % strong acid and 47 % in strong alkaline medium.

- The fracture energy of PVC / PVC specimen plates with glass fiber blended with adhesive decreases in strong acidic and alkaline medium is decreased by 40% in case of epoxy in the strong acid and is decreased by 30% in the strong alkaline, 45 % in case of polyester in strong acid and 35 % in strong alkaline, 39 % in case of poly vinyl acetate in strong acid and strong alkaline 27 % compared to the neutral case.
- The adhesion shear of the PVC / PVC sandwich plates with glass fiber blended with adhesive materials is decreased with increasing the time in both acidic and alkaline medium, and the effect of strong alkaline and acidic medium. The adhesion shear of poly vinyl acetate adhesive material is lower than epoxy and polyester adhesive materials.

Nomenclature

Abbreviation	Description	Unit
a	length of specimen	m
ASTM	American society for testing and materials	
b	width of specimen	m
E	modulus of elasticity	MPa
F	force	kg
H (BHN)	Brinell hardness number	kg/m2
l	length	m.
M	molecular weight	gm /g mole
Min.	minute	
mm	millimeter	
N.m	newton meter	
p	load of the specimen	kg
PVC	poly vinyl chloride	
t	thickness	m
A0	original area	m2
Eg	energy to fracture	N.m/m3
L0	original length	m
σ	strength	MPa
σu	ultimate strength	MPa
Є	strain	mm/mm
ζ	adhesion shear	MPa
∆Є	strain differences	mm/mm
∆ L	length differences	m
Σu	sigma ultimate strength	MPa

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