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The Effect of Fiber-Adhesive Composite on Bond Strength of Plastic Plates- Part II: Adhesive reinforcement

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Abstract: *Pipelines are widely used in the oil and gas industry in both offshore and onshore operations. After several years of operation in corrosive environments, existing steel pipelines may suffer from internal or external metal loss due to erosion and/or corrosion damage mechanisms. More than 60 percent of the world's oil and gas transmission pipelines are more than 40 years old and for the most part in urgent need of rehabilitation in order to re-establish the original operating capacity. Reinforced Epoxy materials are an alternative to carbon steel pipes, which are highly useful especially for corrosive. Aggressive and normal environments. High strength fiberglass and amine cured epoxy resin processed under discontinuous filament winding process is the technology used in reinforced pipes. GRE pipes are suitable and of much use in power plant piping, down hole tubing and casing, plant process piping, oil and gas flow lines, potable water distribution schemes, offshore platform applications and lot more. GRE pipes are comparatively lightweight, easy to handle and install. The thermal conductivity of GRE pipes is low compared to steel and hence heat loss and insulation cost is minimized. GRE pipes also have a smooth internal surface enables high pipe flow capacity and reduces friction as well. GRE pipes, which can be easily installed, are maintenance free. Reinforced pipes present an exceptional arrangement of chemical resistance, thermal resistance, high mechanical properties which is achieved by the selection of highly performing components and a properly designed structure. The purpose of this work is to study the possibility of using the reinforced polymers like poly vinyl chloride (PVC) for natural gas transportation at high pressure approximately 5 MPa instead of using steel pipeline. This type of reinforced polymer will minimize cost and increase the lifetime of the pipeline. The polymer used in the study is poly vinyl chloride (PVC), this type of polymer is widely used in industry more ever it is available and cheap in price. Three types of resins were used at different thickness, epoxy resin, polyester resin and poly vinyl acetate. These resins can make uniform distribution of stress on the reinforced polymer*

Keyword: Composite, glass fiber, epoxy resins, polyester, polyvinyl acetate, PVC.

1- Introduction

Poly Vinyl Chloride (PVC), is the most predominant member of the large family of the polymers and copolymers, is among the most versatile and useful thermoplastics. Other members of the family include copolymers of vinyl chloride and vinyl acetate and polymers of vinyl alcohol [1].

Industrial piping is an essential part of most production and distribution system, not only in chemical and petrochemical facilities but also in almost every industrial installation such as food processes, water works, and natural gas. [2] Many thousands of miles of steel pipeline have been laid under, or in contact with the ground or in atmospheric air for long –distance transport of oil, hot natural gas, etc.… [3].

The environmental conditions causing the pipe to corrode, because the high capital cost of this pipelines, they need to production Poly vinyl chloride. (PVC). The general applications of poly vinyl chloride depend on if it is flexible or rigid films [4]. Flexible poly vinyl chloride tubes are ideally suited for transportation of chemicals; special grades are available for use with foods and for petroleum industry [5]. Rigid poly vinyl chloride sheets are used for fabricating chemical resistant tanks and tank linings, large diameter pipes and ducting for corrosive gases. Rigid poly vinyl chloride pipes have very important uses in food, beverage, drugs and pharmaceuticals, chemical and petroleum industries; they are resistance to many chemicals. These have a long service life and easy to install [6].

The consumption of poly vinyl chloride is increasing rather very sharply. The conventional materials as iron and steel, zinc, lead, and timber are in actuate shortage and imports of these materials cause serious drain in our economy. The poly vinyl chloride fabrication is however the answer [7]. On the other hand, many of our modern technologies require materials with unusual combinations of properties that cannot be met by the conventional metal alloys, ceramics, and polymeric materials. This is especially true for materials that are needed for aerospace, underwater, and transportations applications [8].

Many composite materials are composed of just two phases, one is termed the matrix, which is continuous and surround the other phase, often called the dispersed phase. The properties of composite is a function of the properties of the constituent phases, their relative amount, and the geometry of the dispersed phase. Most composites have been created to improve combinations of mechanical characteristics such as stiffens, toughness, and ambient and high temperature strength [9].

Composite play a very important role in our life, it used in marine industry, aircraft, automobile, leisure, electronic and medical industries are depending on fiber-reinforced plastics, and these composites are routinely designed, manufactured, and used. The success of fiber composite with thermosetting (epoxies and polyesters) or thermoplastic matrix, largely as a replacement for metals, results from the much-improved mechanical properties of the composites compared with matrix materials [10].

The good mechanical properties of the composite are a consequence of utilizing the special properties of glass, carbon, and aramid fibers. The success of fiber composite s results from the ability to make use of the outstanding strength, stiffness, and low specific gravity of fibers such as glass or graphite [11]. When outstanding mechanical properties are combined with the unique flexibility in design capability and ease of fabrication that composites offer, it is no wonder that their growth rate has far surpassed other materials. It is vital that the professional engineer should know how to select material, which best fit the demands of design and economy as well as demands of strength and durability [12].

Marzouk, W.W et al study the tribological behavior of short fibers filled epoxy resin. They showed that, increasing the steel fiber percentage has a market effect on the reduction of both friction coefficient and wear rate of epoxy composites regardless the applied load [13]. S.W. Lye studied the adhesives for bead fusion of recycled expandable polystyrene by blending poly styrene with spray and powder adhesive molding were subjected to five mechanical test, found that the powder adhesives molding can quite offer quite similar material performance except for flexural strength and weight compared with stand a red polystyrene [14].

Bhattacharya, M. studied stress relaxation of starch / synthetic polymer blends. It has been found that the stress relaxation behavior of starch / synthetic polymer blends is similar in many respects to that of synthetic polymers [15]. Jeremy studied the effect of formulating procedure on material properties and performance of adhesive materials, analysis was conducted on materials fabricated with 16% weight but adhesive acrylonitrle reactive rubber, tetra functional epoxies, bisphenol A and epoxies were varied so that to and after cure. Therefore, the formulating procedure affected the performance properties [16-17].

The main objective of this work is to investigate the ability of the use plastics reinforced pipeline for transfer gas at various environmental conditions, because the used pipeline now is made of carbon or stainless steel which has some drawbacks i.e. it's very expensive and need special service like cathodic protection and also the life time of this pipeline is short in spite of its high capital cost. In this study, different types of adhesives are applied between PVC/PVC plates like epoxy, polyester, poly vinyl acetate. The first part from this work is to study the effect of adhesive type and thickness on the bond strength of plastic plates [18].

2- Experimental Method

Material

(1) Polyvinyl chloride (PVC)

Polyvinyl chloride (PVC) which is prepared by the polymerization of the monomer i.e. vinyl chloride, ethylene is more often used these days. Ethylene obtained from cracking of naphtha process of breaking down higher molecular weight petroleum fraction 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 ^oC [18]

$$2\,HCl + \frac{1}{2}\,O + 2\,C_2H_2 \rightarrow 2\,C_2H_4Cl_2 + H_2O \quad (1)$$

Ethylene chloride is subsequently cracked into vinyl chloride

$$C_2H_4Cl \rightarrow CH_2 = CH + HCl \quad (2)$$

Cl

Mechanical properties of PVC thermoplastic are shown in table (1).

Table (1) mechanical properties of PVC thermo plastic

Σu (MPa)	Eg (N.M/m^3)	E (GPa)	H (BHN)	Impact (N.M)	Σu (%)
52	**14**	**1.4**	**26**	**3.5**	**1.1**

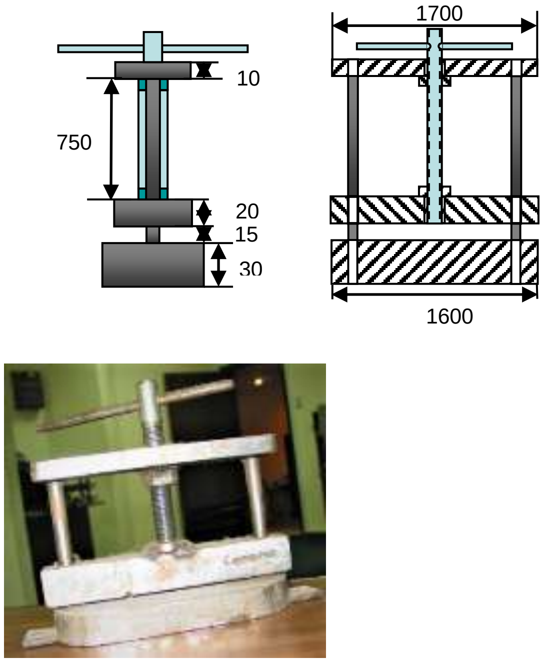


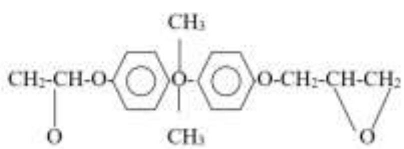
Figure (1): A special press helps to control the thickness of adhesives

Adhesive

Three types of adhesive materials are used in this study and prepared with different thickness. These adhesives are epoxy, polyester and poly vinyl acetate Testing specimens were prepared using a special press and a special stamp to control the thickness, which are shown in Figure (1-2)

(a) Epoxy resin

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



(3)

Epoxy resin was obtained from C.M.B Company (Chemicals for Modern Building), it is two component, solvent free, non-pigmented liquid epoxy resin. It is prepared by blending the hardener with resin with the ratio of 1:2, Epoxy resin 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 thickness (1, 1.5, 2 and 2.5 mm). Mechanical properties of epoxy resin are illustrated in table (2).

Table (2): the mechanical properties of epoxy resin

Σu (MPa)	**Eg ($N.M/m^3$)**	**E (GPa)**	**H (BHN)**	**Impact (N.M)**	**Σu (%)**
75.9	**17**	**3.5**	**30**	**3**	**5.3**

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Figure (2): A special stamp used to control the thickness of adhesive

(b) Polyester

Polyester are formed by the condensation polymerization of a diacid with dialchol (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 in one end of the diacid reacts with the alcohol group on one end of the diol to form a bond linking the two molecules and split out water as a byproduct . The linking group which is formed is called an ester, this step is called condensation reaction. Polyester is prepared by blending the hardener with resin with the ratio of 1:3; it will dry after 24 Hrs. on the PVC samples. Polyester is used as an adhesive between the PVC plates. With different thickness (1, 1.5, 2 and 2.5 mm). Mechanical properties of polyester is illustrated in table (3).

Table (3): the mechanical properties of polyester resin

Σu (MPa)	Eg ($N.M/m^3$)	E (GPa)	H (BHN)	Impact (N.M)	Σu (%)
77	3.4	20	30	4.5	8

(c) Poly vinyl acetate

Crystalline poly vinyl acetate is used as a adhesive material in this study. It should be soluble in a solvent like toluene by heating with indirect heating, then it used as adhesive on the PVC sample. Poly vinyl acetate is used as an adhesive between the PVC plates. With different thickness (1, 1.5, 2 and 2.5 mm). Mechanical properties of poly vinyl acetate are illustrated table (4).

Table (4) Mechanical properties of poly vinyl acetate.

Σu (MPa)	Eg (N.M/m3)	E (GPa)	H (BHN)	Impact (N.M)	Σu (%)
81.5	4.5	23	55	6	11.7

Testing

(1) Tensile test

A universal testing machine was used to obtain 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 rate 5 mm /min (Which the specimen is pulled apart in the test as indicated in ASTM specifications). Maximum load, maximum displacement, ultimate tensile strength and maximum tensile strain were recorded along with load-displacement data. Figure (3) show tensile test specimen.

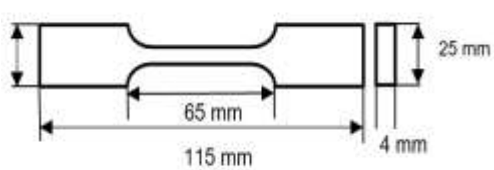

Figure (3): Tensile Test specimen

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

$$\sigma = {}^{P}/_{A_o} \qquad (4)$$

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

$$\epsilon = \frac{L - L_o}{L_o} = \frac{\Delta L}{L_o} \qquad (5)$$

At 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 enough 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 the point, the specimen develops a neck: this is a local decrease in cross sectional area at which further deformation is concentrated. After necking has begun, the engineering stress decreases with further strain until the specimen fractures.

(2) Adhesion shear

This test is very important to determine the adhesion force between the specimen and adhesive. The same universal testing machine was used to obtain shearing load-displacement diagram. 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 in ASTM is a plate with an 11 mm hole drilled through the center of the specimen. Maximum shearing load and maximum shear strength were recorded along with load –displacement data.

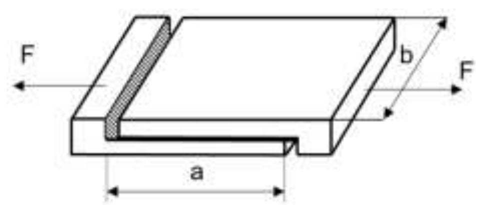

Figure (4): Adhesion shear specimen

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

$$\zeta = \frac{F}{2\,ab} \qquad (6)$$

(3) Impact test

The brooks pendulum impact tester was used; it's for evaluation of plastic materials by Izod test which measures the energy required to rupture a specimen of specific dimensions. This rupture was done by impact 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.

3- Results & Discussion

4.1 Effect of Adhesion Type

a) Tensile behavior of PVC/PVC sandwich plate with 1 mm unfilled adhesive thickness

Tensile behavior of single layer PVC/ PVC sandwich plate having 1mm of three types of adhesives (epoxy resin, polyester, and poly vinyl acetate). is illustrated in Fig. (5). As a result of using adhesive with 1mm thickness, the mechanical behavior is improved significantly compared with single PVC plate. And, the mechanical behavior of PVC/ PVC sandwich plate having 1mm of poly vinyl acetate is better than PVC/ PVC sandwich plate having 1 mm epoxy or polyester. This behavior may be due to different ductility and stiffness of the three kinds of adhesives.

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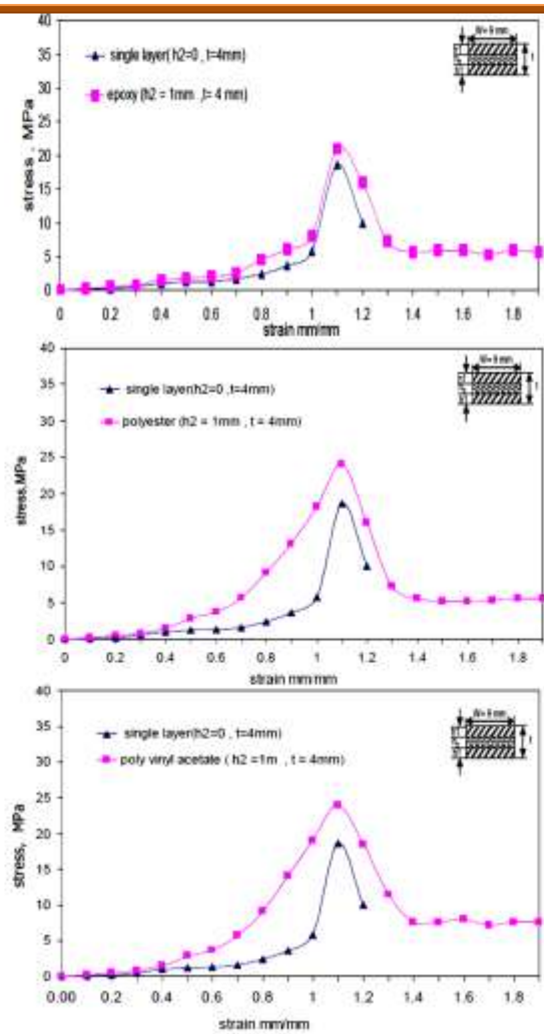

Figure (5): Stress/Strain diagram of PVC/PVC sandwich plate having different resin type.

b) Ultimate strength

Effect of adhesive type on the ultimate tensile strength of PVC/PVC sandwich plates with 1mm adhesive thickness is shown in Figure (6a). The ultimate strength of PVC/PVC sandwich plates increases in the order of epoxy, polyester, and poly vinyl acetate as an adhesion material. The Ultimate strength of PVC/PVC sandwich plates is higher than the single plate of PVC.

c) Modulus of elasticity

Figure (6b) shows the elastic modulus of PVC/PVC sandwich plates having different adhesive types. It is noticed that the elastic modulus of PVC/PVC sandwich plates increases significantly with all adhesive types.

d) Energy to fracture

The energy to fracture (Eg) of PVC/ PVC sandwich plate is calculated as the total area under stress/strain curve, according to the following equation:

$$E_g = \sum_{\epsilon=0}^{\epsilon=\epsilon_f} \Delta\epsilon.\sigma \qquad (7)$$

Energy to fracture of a single layer and PVC/ PVC sandwich plate having different adhesives (epoxy, polyester, poly vinyl acetate) are illustrated in Fig. (6 c). The Energy to fracture increases compared to single layer of PVC. The energy to fracture of PVC/ PVC sandwich plate having of poly vinyl acetate adhesive is the largest value compared with the other adhesive types (epoxy and polyester).

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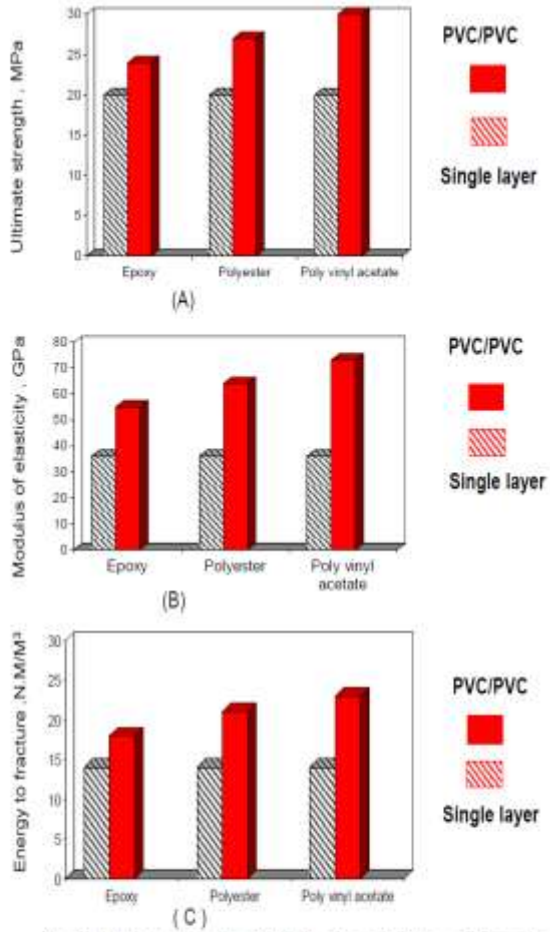

Figure (6): Ultimate strength, Modulus of elasticity and Energy to fracture as a function of adhesive type.

e) Adhesion shear

Figure (8) Shows the adhesion shear of PVC/ PVC Sandwich plate having 1mm thickness of epoxy, polyester, and poly vinyl acetate adhesive layer. The adhesion shear of poly vinyl acetate adhesive is higher than polyester and epoxy adhesive. This may explain the improvement of mechanical properties of PVC/PVC sandwich plates with polyvinyl acetate adhesive type compared with other adhesive types (Epoxy, polyester).

4.2 Effect of Adhesion Thickness

a) Tensile behavior of PVC/PVC sandwich plate with different thickness of unfilled adhesive

Stress/Strain behavior of single layer and PVC/ PVC sandwich plate having different thickness of three types of adhesives epoxy resin, polyester and poly vinyl acetate is illustrated in Figure (9) because of increasing thickness of adhesion layer, the mechanical behavior improved significantly compared with single layer. In addition, the mechanical behavior of PVC/ PVC sandwich plate having different thickness of poly vinyl acetate adhesion layer is better than single plate of PVC / PVC sandwich plate having different thickness of epoxy or polyester. This is due to different ductility and stiffness of the three adhesives.

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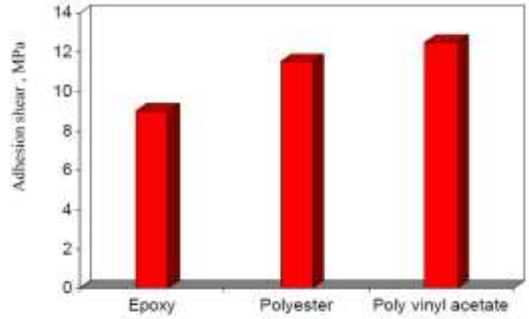

Figure (8): Adhesion Shear of PVC/PVC with 1 mm of three types of Adhesives

a) Ultimate strength

Effect of adhesive thickness on the ultimate tensile strength of PVC/PVC sandwich plates with different thickness of adhesive is shown in figure (10 a). The ultimate tensile strength of PVC/PVC sandwich plate increases because of increasing thickness of the adhesives (epoxy resin, polyester, polyvinyl acetate).

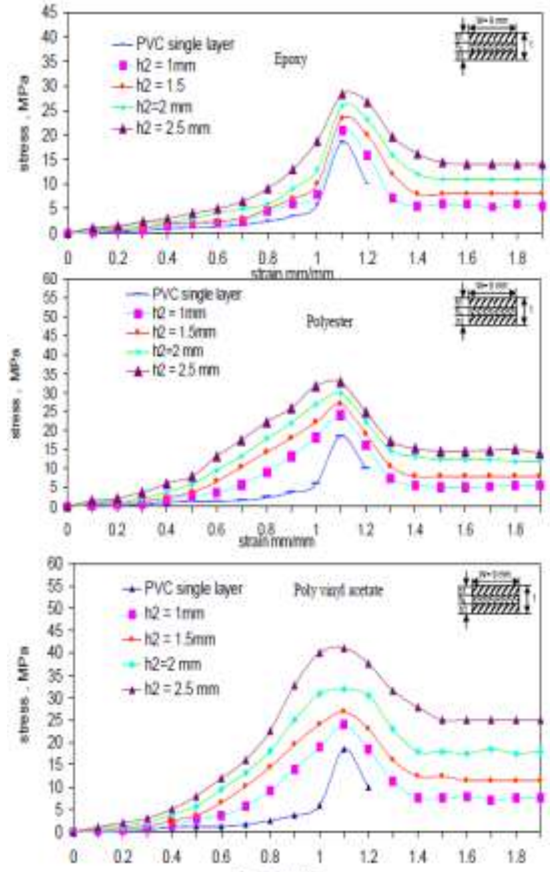

Figure (9): Stress/strain diagram of PVC/PVC sandwich plate having different thickness of adhesive.

b) Modulus of elasticity

Figure (10b) shows the elastic modulus of PVC/PVC sandwich plates having different thickness of different adhesive (epoxy, polyester, poly vinyl acetate). It can be noticed that the elastic modulus of PVC/PVC sandwich plates is slightly affected with increasing adhesive thickness.

c) Energy to fracture

Energy to fracture of a single layer PVC/PVC sandwich plate having different thickness of different adhesives (epoxy, polyester, poly vinyl acetate) is illustrated in Figure (10c). The energy to fracture is slightly increased with different thickness this behavior is consistent with different adhesive types. Energy to fracture of PVC/PVC sandwich plate having different thickness of poly vinyl acetate is higher than polyester and epoxy adhesives.

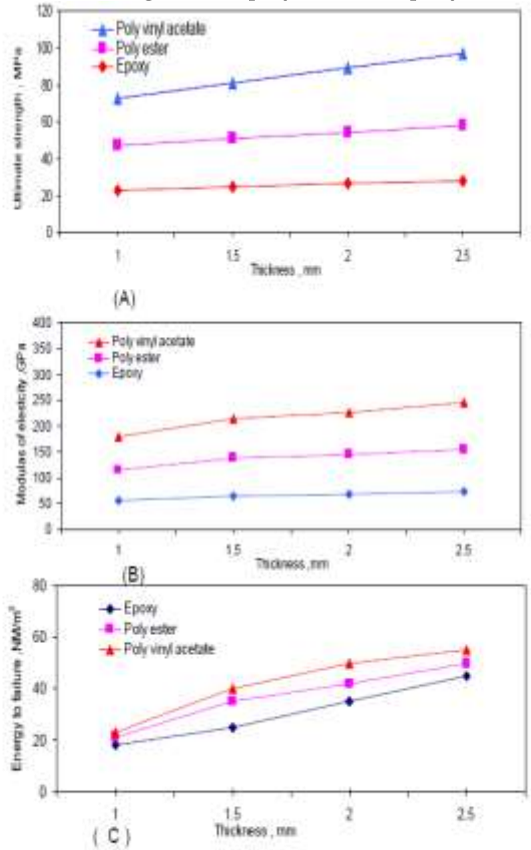

Figure (10): Ultimate Strength, Modulus of elasticity and energy to fracture as a function of adhesive thickness.

d) Impact energy

Fig. (11) Shows the impact energy of single layer of PVC and PVC/ PVC sandwich plate having different thickness of adhesives (epoxy, polyester, and poly vinyl acetate). The energy absorbed increases with increasing the thickness of adhesive compared with single layer of PVC. The energy absorbed for PVC/ PVC sandwich plate having different thickness of poly vinyl acetate is higher than polyester and epoxy resin.

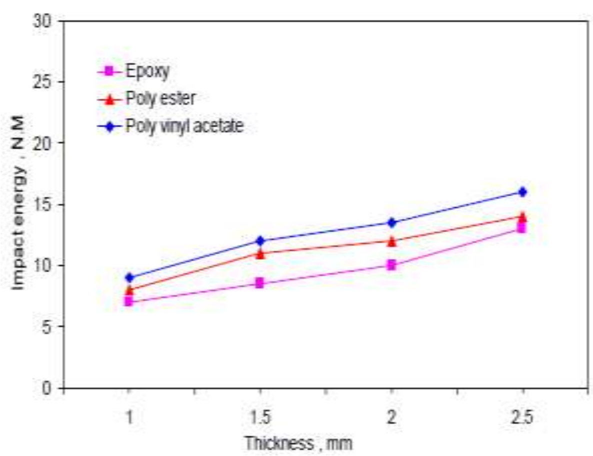

Figure (11): Impact of energy of PVC/PVC with different thickness.

e) Adhesion shear

Figure (12) shows the adhesion shear of PVC/ PVC Sandwich plate having different thickness of adhesives (epoxy, polyester, and poly vinyl acetate). The adhesion shear increases with increasing the thickness of adhesive. Adhesion shear of poly vinyl acetate adhesive layer with different thickness is higher than polyester and epoxy adhesives. This may explain the improvement of mechanical properties of PVC/PVC sandwich plates with poly vinyl acetate adhesive thickness compared with other adhesives (epoxy, polyester).

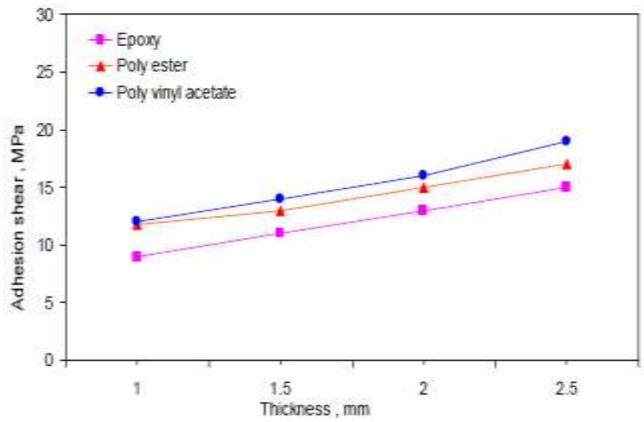

Figure (12): Adhesion shear of PVC/PVC with different thickness.

4- Conclusions & recommendations

From the study of the effect of fiber adhesives composite on bond strength of plastic plates the following conclusions can be drawn:

i. Mechanical properties of PVC /PVC sandwich plates are higher than PVC single plate having the same cross section, and its thickness depending on the kind of adhesive as following: -

ii. Strength of PVC/PVC sandwich plates depending on the adhesive thickness increased significantly by 50% in case of epoxy, 65 % in case of polyester, 100% in case of poly vinyl acetate.

iii. Energy to fracture of PVC/PVC sandwich plates increased by 57% in case of epoxy, 77% in case of polyester and 90 % in case of poly vinyl acetate compared to the single PVC having the same cross section.

iv. Adhesion shear of PVC/PVC sandwich plate increased longingly by increasing adhesive thickness, and the adhesion shear of poly vinyl acetate is higher than epoxy and polyester.

Nomenclature

Abbreviation	**Description**	**Unit**
a	Length of specimen	m
b	Width of specimen	m
d	Diffusion rate	m^2/s
E	Modulus of elasticity	MPa
F	Force	Kg
H (BHN)	Brinell hardness number	Kg/m^2
I	Impact energy	MPa
M	Molecular weight	gm /gmole
N	Degree of polymerization	
PVC	Poly vinyl chloride	
t	Thickness	m
T	Temperature	K
V	Molar volume	m^3
W	Width	m
A0	Original area	m^2
Ac	Surface area of composite	m^2
Ap	Surface area of polymers	m^2
Am	Surface area of matrix	m^2
Ec	Modulus of elasticity of composite	MPa

E g	Energy to fracture	$N.M/m^3$
E F	Modulus of elasticity of fiber	MPa
Em	Modulus of elasticity of matrix	MPa
E0	Preexponentinl	m^2/s
Fc	Load carried by composite	MPa
Fm	Load carried by composite	MPa
Fp	Load carried by Polymer	MPa
Vc	Volume of composite	m^3
VF	Volume of Fiber	m^3
Vm	Volume of matrix	m^3
Vp	Volume of Polymer	m^3
Wa	Thermo dynamic work of adhesion	N.M
Lo	Original length	m
Lmd	The length of micro defect	m
σc	Tensile strength of composite	MPa
σf	Tensile strength of fiber	MPa
σm	Tensile strength of matrix	MPa
ɤ	Surface tension	N/m
ɤL	Surface tension of a liquid	N/m
ɤlv	Surface tension of a liquid equilibrium with vapor	N/m
ɤsl	Interfacial energy	kJ
δs	Solubility parameter	
π	Equilibrium spreading pressure	MPa
σ	Strength	MPa
σc	yield strength	MPa
σu	Ultimate strength	MPa
Є	Strain	mm/mm
Єf	Fracture strain	mm/mm
Єc	Strain of composite	mm/mm
Єm	Strain of matrix	mm/mm
Єf	Strain of fiber	mm/mm
Єc	Strain of composite	mm/mm
ζ	Adhesion shear	MPa
ΔЄ	Diff. in strain	mm/mm
Δ H	Diff. in molar heat of vaporization	kJ
Δ L	change in length	m

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