407 Egypt. J. Chem. **Vol. 63,** No. 12 pp. 5145-5159 (2020)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

The Effect of Fiber-Adhesive Composite on Bond Strength of Plastic Plates-Part I: Adhesion Type & Thickness

Ebrahiem Esmail Ebrahiem[1,*], Ahmed Abdelaziz Noaman[1], Ibrahim Hamed M. Aly[1], Mostafa A. Abdel-Rahman[2].

[1] Chemical Engineering, [2] Production & Design Engineering, Faculty of Engineering - Minia University, Egypt

Abstract

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 to re-establish the original operating capacity. So, these steel pipelines may suffer from internal or external metal loss due to erosion and/or corrosion.

Reinforced Epoxy materials as an alternative to carbon steel pipes are highly useful especially for corrosive. They present an exceptional arrangement of chemical resistance, thermal resistance, high mechanical properties which is achieved by the selection of high performing components and a properly designed structure. The reinforced polymers like poly vinyl chloride (PVC) for natural gas transportation at high pressure (approximately 5 MPa) are investigated to be used instead of steel pipeline. Polyvinyl chloride (PVC) polymer is used. Three types of resins (epoxy, polyester, and poly vinyl acetate) were used with different thickness. These resins can make a uniform distribution of stress on the reinforced polymer.

The results shows the strength of PVC/PVC sandwich plates is higher than PVC/PVC single plate by 50 % for epoxy, 65% for polyester and 100% in case of poly vinyl acetate, moreover the poly vinyl acetate gave best results for energy to fraction and adhesion shear tests.

Keyword: Oil industry, corrosion and/or erosion, steel pipeline, epoxy resins, PVC.

1. Introduction

Polyvinyl Chloride (PVC) is the most predominant member of the large family of the polymers and copolymers. It 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 petroleum industry [5].

*Corresponding author e-mail: prof.ebrahiem@mu.edu.eg; (Ebrahiem E. Ebrahiem).
Receive Date: 28 July 2019, Revise Date: 25 May 2020, Accept Date: 22 June 2020
DOI: 10.21608/EJCHEM.2020.15361.1932

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 a 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 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 surrounds 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].

Alaa I Eid et al studied the physico mechanical and electrical properties of polypropylene/Nano- copper composites for industrial applications, the results showed a significant enhancement of the composite behavior up to 1.5 wt.% of nano particles addition the fabricated composites with different nano-copper contents have large finding with different applications [17].

In this work, the study of using plastics reinforced pipeline for transfer gas at various environmental conditions is investigated to replace of carbon or stainless steel pipeline which required a very expensive and special service like cathodic protection and also its lifetime is shorter although its high capital cost. A different type of adhesives are applied between PVC/PVC plates like epoxy, polyester, poly vinyl acetate. The effect of adhesive type and thickness on the bond strength of plastic plates

2. Experimental Materials and Method

2.1 Material

2.1.1 Polyvinyl chloride

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 30-50C°.

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

Ethylene chloride is subsequently cracked into vinyl chloride

$$C_2H_4Cl \longrightarrow CH_2{=}\underset{\displaystyle CL}{\underset{|}{C}}H+HCL$$

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 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 Fig. (1 & 2)

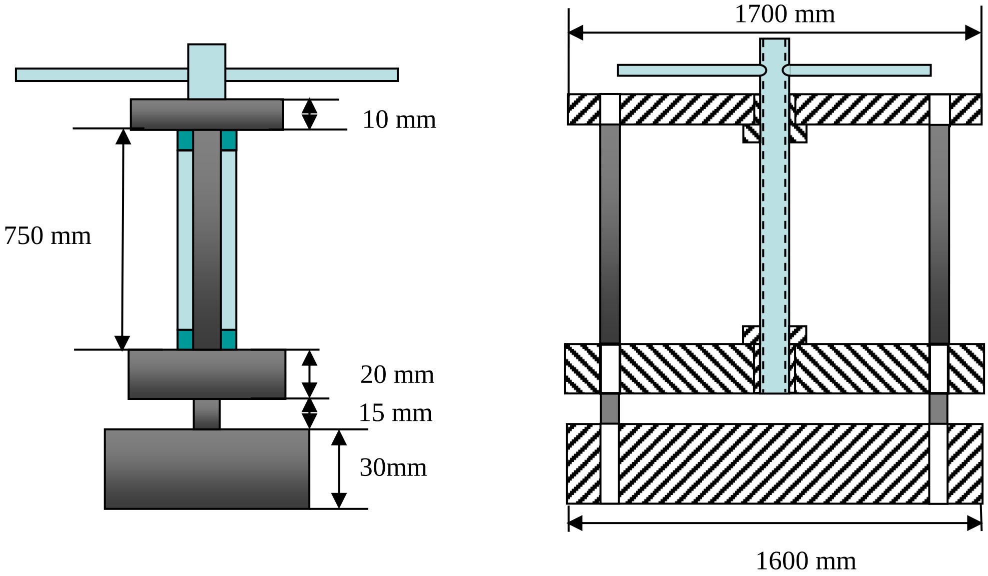
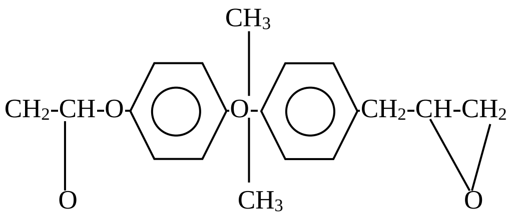


Fig. (1) A special press helps to control the thickness of adhesives

Fig. (2) A special stamp used to control the thickness of adhesive

2.1.2.1. Epoxy resin

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



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 (1)

2.1.2.2. 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 dialchol, 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 by-product. 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 (1).

2.1.2.3. Poly vinyl acetate

Crystalline poly vinyl acetate is used as an 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 (1). Table (1) reveals the mechanical properties of polyvinyl chlorides and different resins

Table (1) Mechanical Properties of Polyvinyl chloride and Different Resins

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

2.2. Testing

2.2.1. 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 [18, 19]). Maximum load, maximum displacement, ultimate tensile strength, and maximum tensile strain were recorded along with load-displacement data. Figure (3) reveals tensile test specimen.

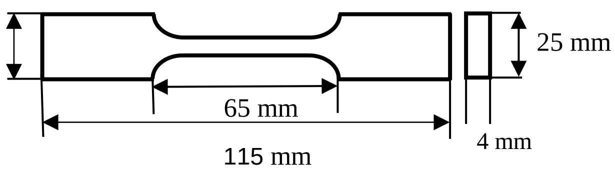


Fig (3) Tensile Test Specimen

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)

$$\sigma = P/A_o$$

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

$$\epsilon = L - Lo / Lo = \Delta L/Lo$$

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 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 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.

2.2.2. 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) illustrates the adhesion shear specimen used.

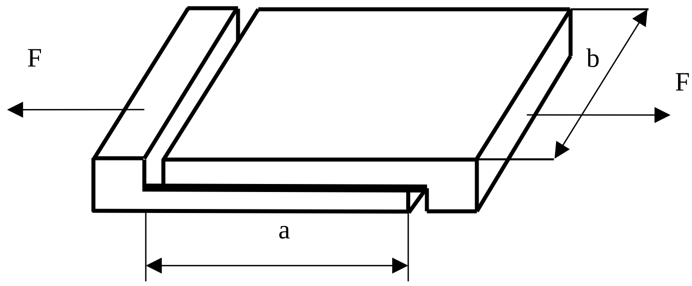


Fig. (4) Adhesion shear specimen

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

$$\zeta = F/2ab$$

2.2.3. 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 encounters 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

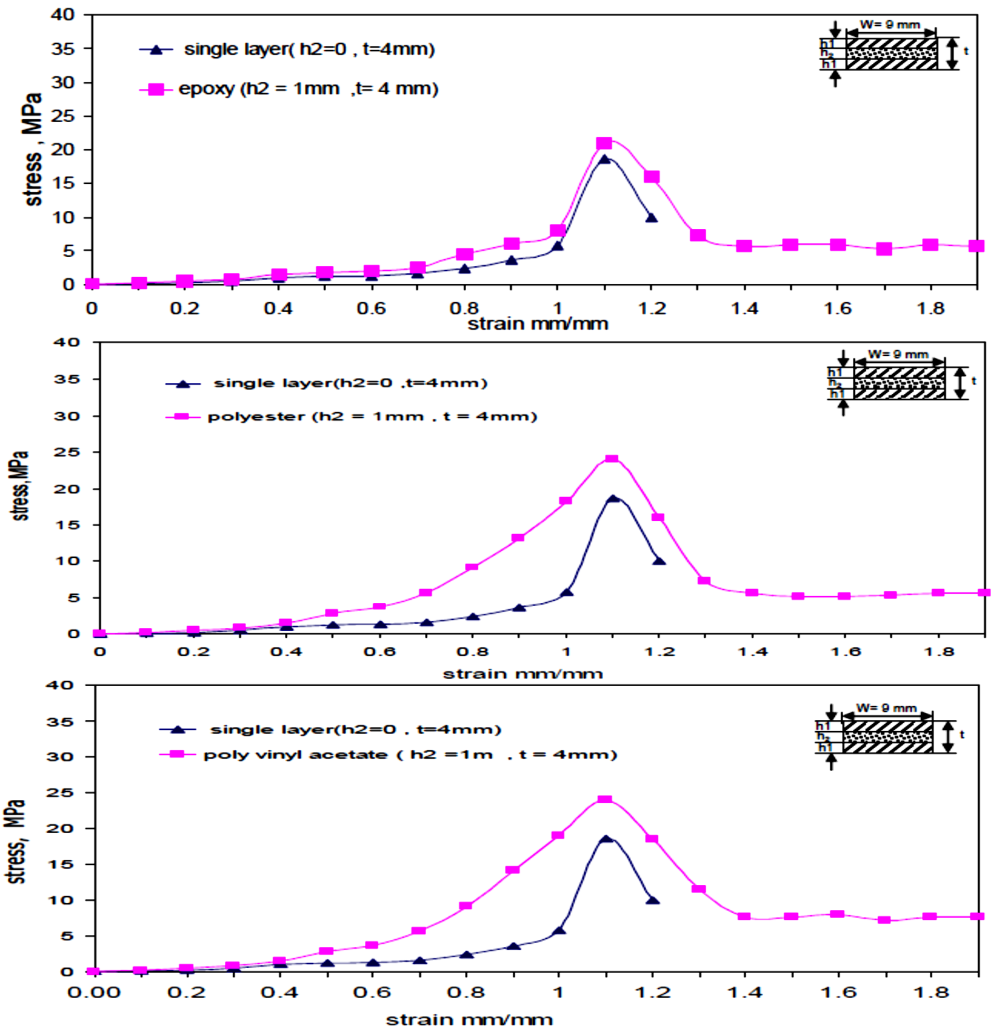
3.1. Effect of Adhesion Type

3.1.1. Tensile behaviour of PVC/PVC sandwich plate with 1 mm unfilled adhesive thickness

Tensile behaviour of single plate 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 behaviour is improved significantly compared with single PVC plate.

And, the mechanical behaviour 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 behaviour may be due to different ductility and stiffness of the three kinds of adhesives.

Fig.(5) Stress /Strain Diagram of PVC/PVC Sandwich Plate Having Different Resin Types



3.1.2. Ultimate strength as a Function of Adhesive Type

Effect of adhesive type on the ultimate tensile strength of PVC/PVC sandwich plates with 1mm adhesive thickness is shown in Fig. (6 a). 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.

3.1.3. Modulus of elasticity as a Function of Adhesive Type

Fig. (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.

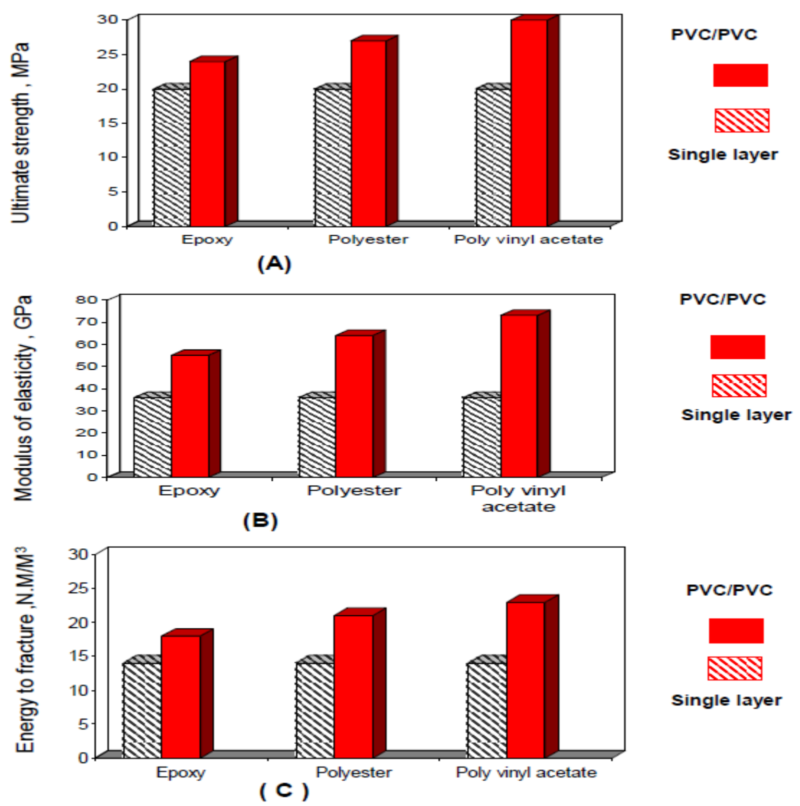
3.1.4. Energy to fracture as a Function of Adhesive Type

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

$$E_g = \sum_{\epsilon=0}^{\epsilon=\epsilon_f} \Delta\epsilon . \sigma$$

Energy to fracture of a single plate 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 plate 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).

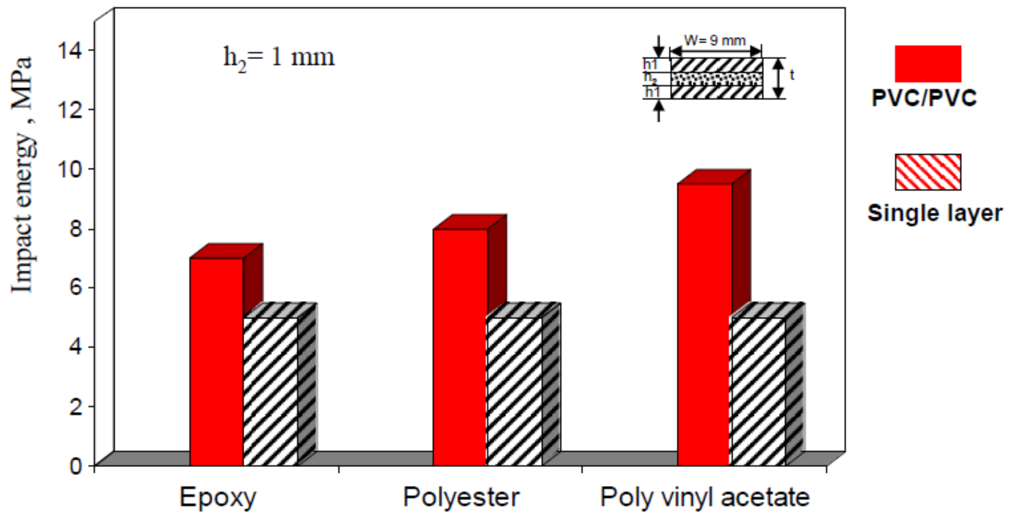
Fig.(6) Ultimate strength , Modulus of Elasticity and Energy to Fracture as a Function of Adhesive Type



3.1.5. Impact Energy of PVC/PVC with 1mm of Different Adhesives

Fig. (7) shows the impact energy of single plate and PVC/PVC sandwich plates having 1mm thickness of different adhesive (epoxy, polyester, poly vinyl acetate). The energy absorbed for PVC/PVC sandwich plate having 1 mm of poly vinyl acetate is higher than polyester and epoxy adhesive.

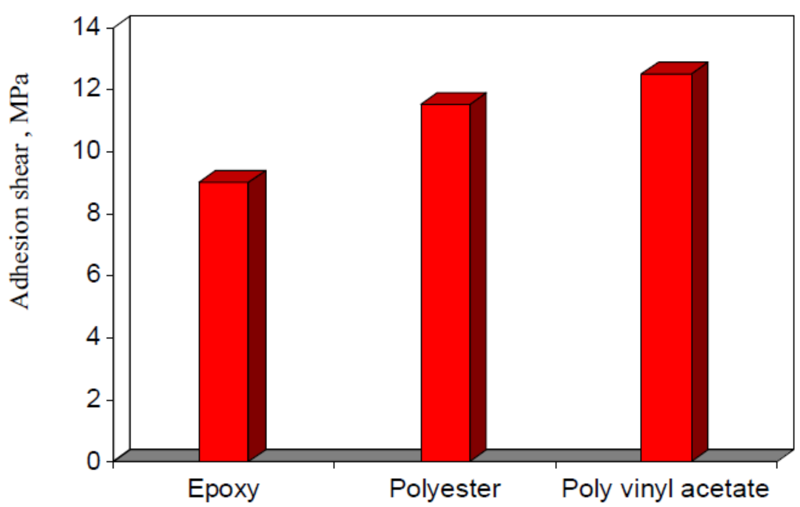
Fig. (7) Impact energy of PVC/PVC with 1mm Thickness of three types of adhesives



3.1.6. Adhesion shear of PVC/PVC with 1mm of Different Adhesives

Fig. (8) Illustrates the adhesion shear of PVC/ PVC sandwich plates having 1mm thickness of epoxy, polyester, and poly vinyl acetate adhesive plate. 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).

Fig.(8) Adhesion Shear of PVC/PVC with 1mm Thickness of Three Types of Adhesives



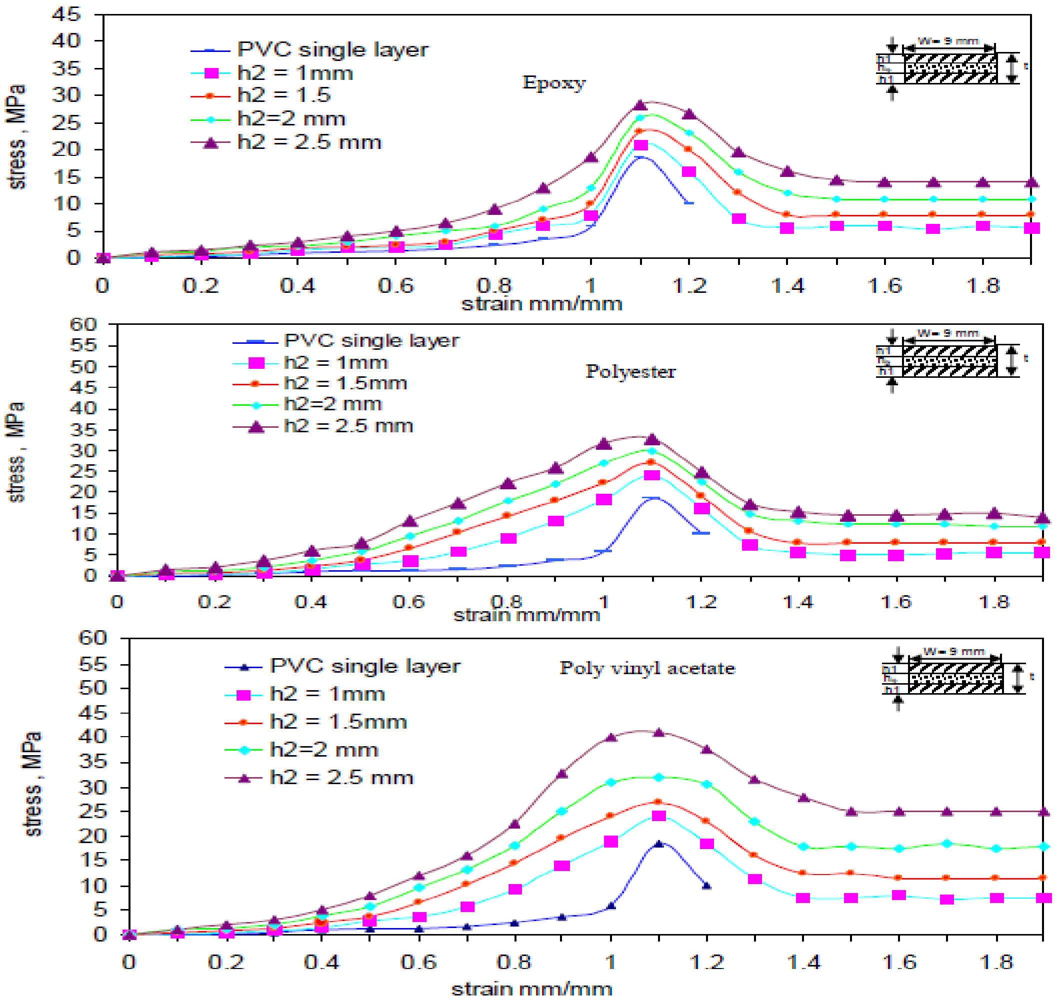
3.2. Effect of Adhesion Thickness

3.2.1. Tensile behaviour of PVC/PVC sandwich plate with different thickness of unfilled adhesive

Stress – Strain behaviour of single plate and PVC/ PVC sandwich plates having different thickness of three types of adhesives epoxy resin, polyester and poly vinyl acetate is illustrated in Fig. (9). because of increasing thickness of adhesion layer, the mechanical behaviour improved significantly compared with single plate.

In addition, the mechanical behaviour of PVC/ PVC sandwich plates having different thickness of poly vinyl acetate adhesion plate is better than single plate of PVC / PVC sandwich plates having different thickness of epoxy or polyester. This is due to different ductility and stiffness of the three adhesives.

Fig.(9) Stress /strain Diagram of PVC/PVC Sandwich Plate Having Different Thickness of Adhesive



3.2.2. Ultimate strength as a Function of Adhesive Thickness

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 plates increases because of increasing thickness of the adhesives (epoxy resin, polyester, and poly vinyl acetate).

3.2.3. Modulus of elasticity as a Function of Adhesive Thickness

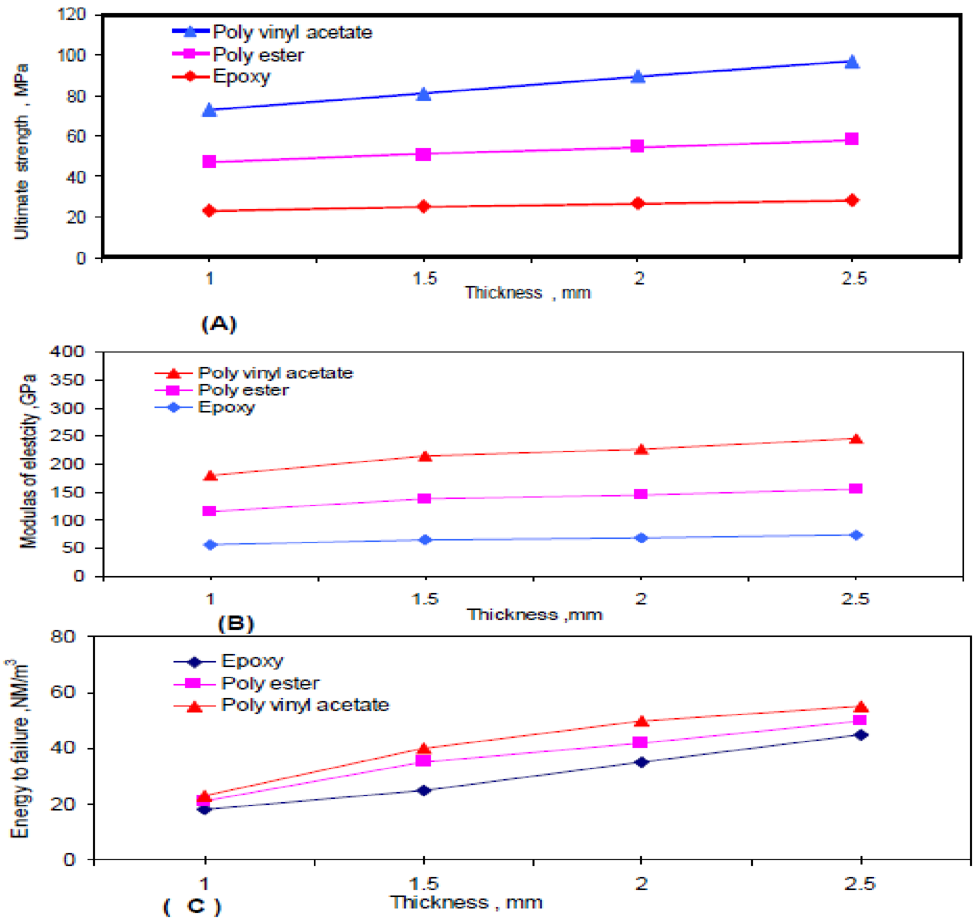
Fig. (10 b) reveals the elastic modulus of PVC/PVC sandwich plates having different thickness of different adhesive (epoxy, polyester, poly vinyl acetate). It can be noticed that the elastic modulus of PVC/PVC sandwich plates is slightly affected with increasing adhesive thickness.

3.2.4. Energy to fracture as a Function of Adhesive Thickness

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

Energy to fracture of PVC/PVC sandwich plates having different thickness of poly vinyl acetate is higher than polyester and epoxy adhesives.

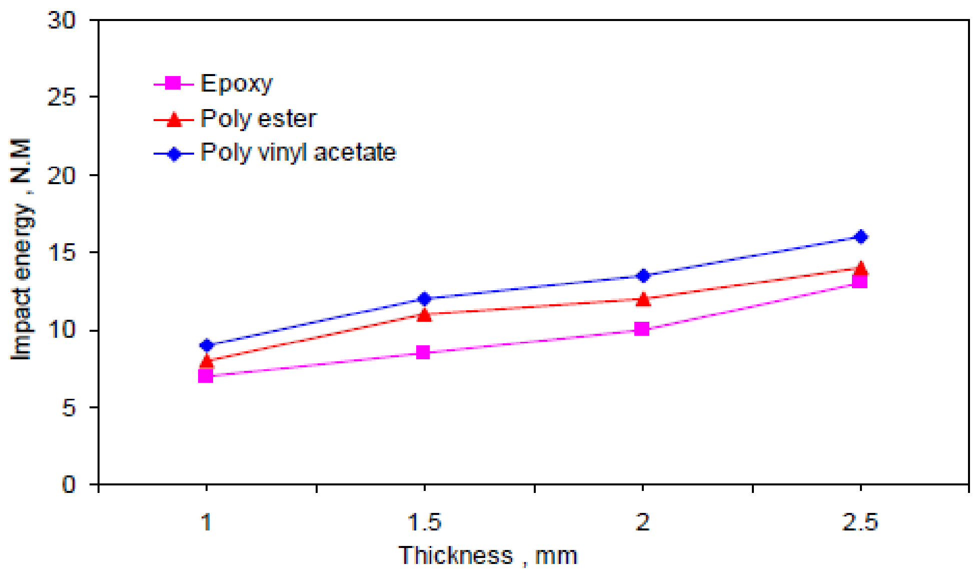
Fig.(10) Ultimate strength , Modulus of Elasticity and Energy to Fracture as a Function of Adhesive Thickness



3.2.5. Impact energy of PVC/PVC with Different Thickness

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

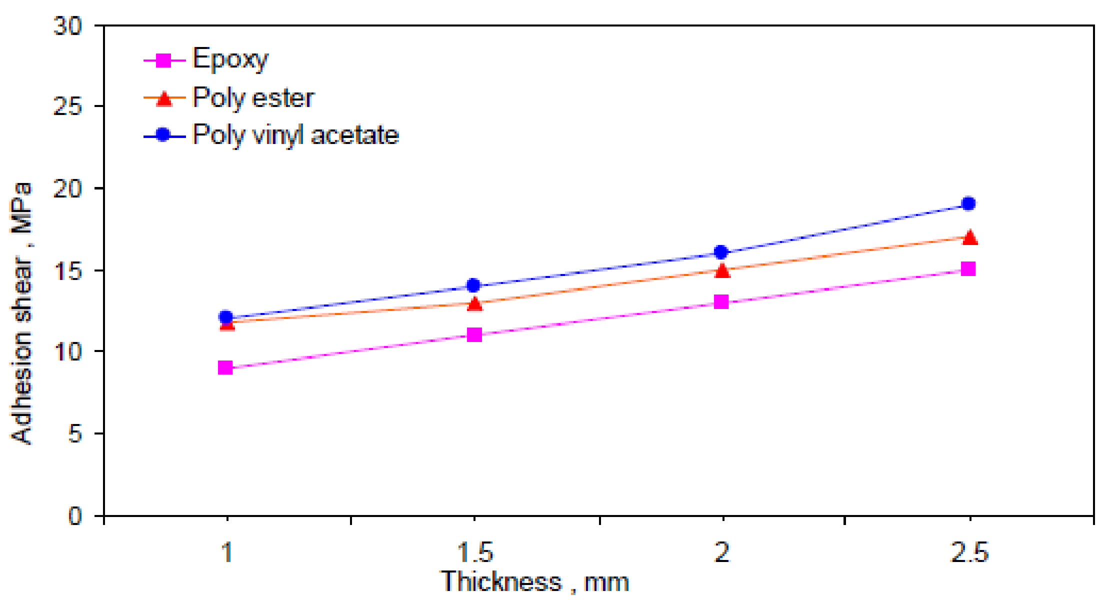
Fig.(11) Impact energy of PVC/PVC with different thickness of Adhesive



3.2.6. Adhesion shear of PVC/PVC with Different Thickness

Fig. (12) displays the adhesion shear of PVC/ PVC Sandwich plates 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).

Fig.(12) Adhesion shear of PVC/PVC with different thickness of Adhesive



4. Conclusions & recommendations

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

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: -

a) 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.
b) 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 plate having the same cross section.
c) 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.

The best fibre adhesives composite from the 3 different types used was ploy vinyl acetate

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	meter
M	Molecular weight	gram /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
E g	Energy to fracture	N.M/m3
L0	Original length	meter
σ	Strength	MPa
σu	Ultimate strength	MPa
Є	Strain	mm/mm
Єf	Fracture strain	mm/mm
Єf	Strain of fiber	mm/mm
ζ	Adhesion shear	MPa
ΔЄ	Diff. in strain	mm/mm
Δ L	change in length	m
Σu	Sigma ultimate strength	MPa

5. Conflicts of interest

There are no conflicts to declare.

6. Funding sources

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
The authors will be responsible for their financial interest

References

[1] Weber A., " Plastics in Automotive Engineering Use and Reuse ", J. of Material Design, Vol. 12, (1991), 48-50.

[2] Wolfe Donald, Baron John J, " Flexible Pipe Combats Corrosion Threat at Sour Brine Injection Site ", Oil and Gas J., Vol. 95, (1997), 48-51.

[3] Michael, F Ashbs, David R. Zenes, "Eng. Materials ", Pub. R. Maxwell, Vol. 34, (1980), 214-219,

4] Comyn, J. (Ed), "Polymer Permeability", Appl. Sci. Pub., London, (1985).

[5] R.P. Wool, "New Trends in Physics and Physical Chemistry of Polymers", Plenum Press, New York, (1999), 129.

[6] H. F. Mark, N.M. Bikales, C.G. Overberger, and G. Menges, Eds., " Encyclopedia of Polymer Sci. and Eng. ", 2nd Ed. Vol. 17, John Wily & Sons, New York, (1989), 204.

[7] R.P. Wool, "Polymer Interface Structure and Strength", Hanser Pub., Munich, (1995).

[8] Zerfin RB, Scholten Fl, " Influence of Natural Gas Constituent on Plastics Used in Gas Networks ", Intern. Conf. Plastic Pipe, (1985), 42.1.

[9] Ordu Pierre, Poirette Yann, Abergel Laurent, " Composite Riser and Export Line or Deep offshore Applications ", The Intern. Conf. on Offshore Mechanics and Article Eng. – OMAE, Vol.3, (2003), 147-156.

[10] Marzouk, M.S., Abdel Rahman, M.A., " Tensile Behavior of Textile Fatigue Limit and Mechanical Properties Relationship of Textile Laminates Filled Recycled Thermoplastic'', MICATE' Conf. 99, Faculty of Eng., Minia Unv., Vol. 5, (1999), 180-190.

[11] Raymond, B. Seympour, " Reinforced Plastics (Properties And Applications) ", AME Intern. (1991).

[12] Creton, "C. Materials Sci. and Technology: A Comprehensive Treatment VCH: ", Weinheim, Germany, (1997), 18,708.

[13] Word, I.M Hadley, D.W.," Introduction to The Mechanical Properties of Polymers ", John Wiley, New York, (1993).

[13] Marzouk, M.S., Abdel Rahman, M.A., Hashem, A.M., " Tensile Behavior of Textile Laminates Filled Recycled Thermoplastics", ICATE' Conf. 99, Faculty of Eng., Minia Unv., Vol. 5, (1999), 191-200.

[14] S. W. Lye, H. S .AW, S. G. Lee, "Adhesives for Bead Fusion of Recycled Expandable Polystyrene ", J. of Polymer Sci. Part A: Vol. 71 Issue 8, (1999), 651-663.

[15] Bhattacharya, M., " Stress Relaxation of Starch /Synthetic Polymer Blends", J. of Material Sci., Vol. 33, (1998), 4131-4139.

[16] Jeremy H.Kilug, James C. Seferis, ''Model High –Performance Adhesive Systems '', J. of Polymer Sci. Part A: Vol. 71 Issue 5, (1999), 651-663.

[17] Alaa Eid, Omayma A. Elhady, LamiaaZ., " studying of physico- mechanical and electrical properties of polypropylene/ Nano- copper composite for industrial Applications" , Egypt journal Chemistry, Vol. 62, No.5, (2019), 916- 920.

[18] ASTM D 5083, 1996. Tensile Properties of Reinforced Thermosetting Plastic Using Straight-Sided Specimens.

[19] ASTM: D695-96. Standard test method for compressive properties of rigid plastics. West Conshohocken (PA): ASTM Int., 1996.