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Mechanical Properties of Hybrid Composite Pipe

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By

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بسم الله الرحمن الرحيم

قَالُواْ سُبْحَانَكَ لاَ عِلْمَ لَنَا إِلاَّ مَا عَلَّمْتَنَا إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيمُ

صدق الله العظيم

سورة البقرة

الاية (32)

Dedication

This work is dedicated with

all my Love and Respect to:

The spirit of my father

My Kind mother

My Husband "Mahmoud" for his patience, understanding and support for each step in my way

My Lovely Brothers

My lovely sister

My Friends

Amani Jamal Abdulrahman

2018

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The researcher

Amani Jamal Abdulrahman

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Abstract

This study investigates in the mechanical properties of composites materials which is used in the manufacturing of pipelines.

Two types of binary blends for the matrix materials consisting (Epoxy-10%, 15%, 20% Resole) and (Epoxy- 2%, 4%, 6% Polysulfide rubber) were prepared, then both two blends were tested mechanically with (tensile, hardness, impact and flexural) and the best mechanical properties were for the blends of (90% Epoxy-10% Resole) and (98% Epoxy- 2% Polysulfide) which are chosed to be reinforced it in the next stage.

Two types of fibers (carbon fibers, glass fibers) with one weight fraction (20%) were used to reinforce the best percentage for both types of binary blends. Fibers were used to reinforce composites materials with four types of reinforcement as**:** reinforced matrix with three layers of carbon fibers, reinforced matrix with three layers of glass fibers, reinforced matrix with two layers of carbon fibers and one layer of glass fibers (carbon, glass, carbon) and reinforced matrix with two layers of glass fibers and one layer of carbon fibers (glass, carbon, glass). Various mechanical tests were carried out on test samples: tensile, impact, hardness, bending and wear, as well as the physical test (absorption test). The results of all reinforced hybrid composites showed an increase in all mechanical properties. The obtained results determined the best composite material blend that suitable for the manufacturing of pipelines applications after comparing the properties of hybrid composite blends with materials used for manufacturing pipe where the sample was which reinforced by three layers of carbon fibers for (Ep- 2% Ps) blend has the best mechanical properties.

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List of Symbols

Symbol	Definition	Units
σ_T	Tensile Strength	MPa
E	Young`s Modulus	GPa
ρ	Density of material	g/cm^3

v_c	Volume fraction of composite	-
v_m	Volume fraction of matrix	-
v_r	Volume fraction of reinforcement	-
W_C	Weight fraction of composite	-
W_m	Weight fraction of matrix	-
W_r	Weight fraction of reinforcement	-
w_m	Weight of matrix	Kg
w_r	Weight of reinforcement	Kg
w_c	Weight of composite	Kg
ρ_c	Density of composite	g/cm³
ρ_m	Density of matrix	g/cm³
ρ_r	Density of reinforcement	g/cm³
v_m	Volume of matrix	cm³
v_r	Volume of reinforcement	cm³
v_c	Volume of composite	cm³
F_c	The totle load sustained by the composite	KN
F_m	The load carried by the matrix phase	KN
F_r	The load carried by the fiber phase	KN
σ	Tensile strength	MPa
P	The applied load	N
A	Cross- sectional area	m²
ε	Strain	-

List of Abbreviations

Abbreviations	Meaning
ASTM	American Standard for Testing Materials
CF	Carbon Fibers
CFRP	Carbon fiber-reinforced Plastic
DSC	Differential scanning calorimetry
Ep	Epoxy Resin
FRC	Fiber Reinforced Composites

FRP	Fiber Reinforced Plastic
GF	Glass Fibers
GFRP	Glass fiber reinforced plastic
HRC	Hybrid Reinforced Composites
LRC	Laminate Reinforced Composites
Ps	Polysulfide Rubber
Re	Resole Resin
SEM	Scanning electron microscopy
Shore D	Shore Durometer
Tg	Glass transition temperature
UTS	Ultimate tensile strength
Wt %	Weight content ratio

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Chapter One

Introduction and Literature Survey

Chapter one

INTRODUCTION AND LITERATURE SURVEY

1.1 Introduction

Many of the modern industrial applications and technologies required materials with superior properties that cannot be met by conventional monolithic materials, such has metal alloys, ceramics and polymers. Because of their heterogeneous nature composite materials have several advantages over traditional engineering materials, which make them attractive for many industrial applications. Properties of composites arise as a function of its constituent materials, their distribution, and the interaction among them and as a result an unusual combination of material properties can be obtained. Composite materials have superior mechanical properties like high specific stiffness, high specific strength, high fatigue strength and good impact properties. From thee wide family of composites, fiber reinforced composites have taken much attention due to their good mechanical properties. These composites have found a wide range of application area due to their anisotropic nature, the direction dependence of their properties results in much better design flexibility that cannot be obtained by monolithic materials or particle reinforced composites [1].

Recently, underground fiber reinforced plastic (FRP) pipes serve in diverse applications such as sewer lines, water mains, gas lines, culverts, oil lines, etc. It is now possible to use engineering science to design these underground pipes with a degree of precision comparable with that obtained in designing buildings and bridges [2].

Almost all of buried pipes can be classified as either flexible or rigid, depending on how they perform when installed. Flexible pipes take advantage of their ability to move, or deflect, under loads without structural damage. Common types of flexible pipes are manufactured from polyethylene (PE), polyvinyl chloride (PVC), steel, glass fiber reinforced thermosetting polymer plastic (GFRP), and aluminum. Both flexible and rigid pipes require a proper backfill to allow the load transfer from the pipe to the soil.

When a flexible pipe deflects against the backfill, the load is transferred to and carried by the backfill. When loads are applied to rigid pipes, on the other hand, the load is transferred through the pipe wall into the bedding material [3].

FRP is generally thinner, lighter, and harden than the existing concrete or steel pipes lines, and it is excellent in stiffness/strength per unit weight. Therefore, FRP is good for construction when it is buried underground and can reduce the failure risk of materials. In particular, as thick soft grounds exist, there are many large scale residential development areas with poor soil condition, and high banking sections and bury depths have tendency to be deeper. As a result of it, the applications of FRP pipes are expected to increase sharply. In FRP pipes, since the reinforcing fiber is arranged in the circumferential direction due to the characteristics of manufacturing process, the mechanical property of material can be considered orthotropic in which the circumferential and longitudinal directions of mechanical properties of pipe are different each other. Therefore, the coupling effects, which do not occur in the isotropic materials of member deformations, can occur, and the structural behaviors can be considerably different from that of the existing cast steel and concrete pipes which are assumed to be composed of isotropic materials. Due to the mechanical characteristics of FRP which has different mechanical properties according to the type of reinforcing fiber, stacking angle, and the type of resin, FRP pipes have merits to design the material properties satisfying required performance, meanwhile, it should be designed and constructed considering the field conditions, because manufacturers use different materials in characteristics.

As mentioned earlier, FRP pipes derives their soil load carrying capacity from their flexibility. Under soil load the pipe tends to deflect thereby, developing passive soil support at the sides of the pipe. At the same time, the ring deflection relieves the pipe of the major portion of the vertical soil load which is supported by the surrounding soil in an arching action over the pipe. The effective strength of the flexible pipe-soil system is significantly high.

When a FRP pipe is buried in the soil, the pipe and soil then work as a system in resisting the load, Figure (1-1) shows that the deflection of the pipe is a function of the load on the pipe, but the load on the pipe is a function of the deflection. The reduction in load imposed on a pipe because of its flexibility is sometimes referred to as arching [4].

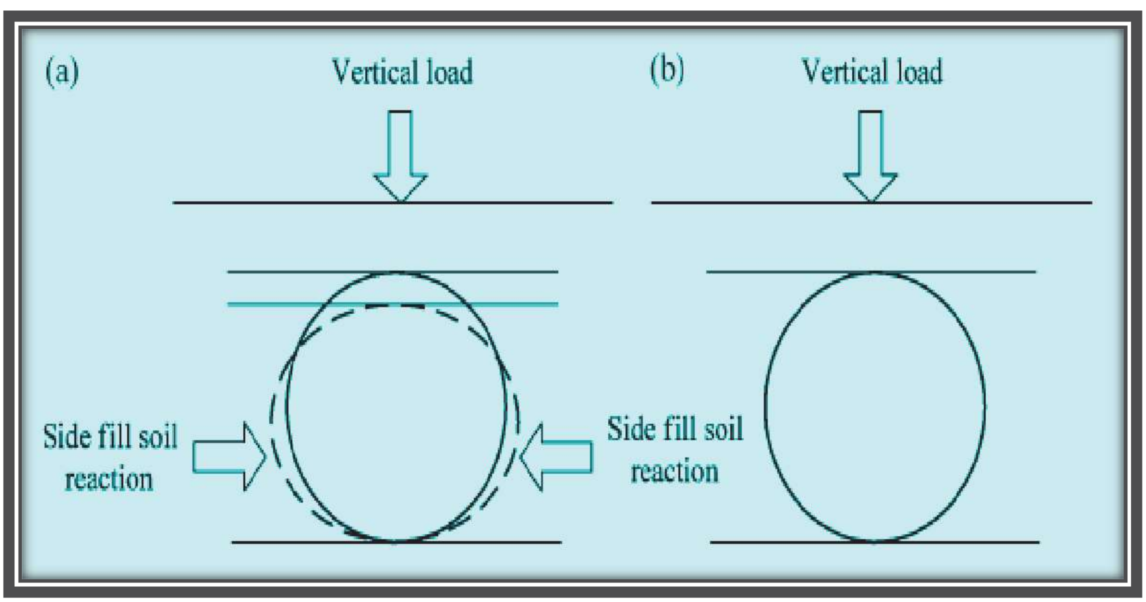

Figure (1-1): Load transfer mechanism of flexible pipe (a) Flexible pipe (b) Rigid pipe (no deformation) [4].

In general, failure of pipelines are extremely serious and have major consequences in terms of economic loss, social impacts and environmental issues. The failure of a pipe occurs when the applied stresses in the pipe exceeds the structural capacity of the pipe. The structural capacity reduced over time due to material deterioration, the mechanisms which are dependent on the pipe material. The failure in the pipes and joint result from a combination of many causes such as operational condition (i.e., traffic load and pressure load), environmental factors (i.e., soil corrosivity and reactivity) and intrusion (i.e., third party damage). Figure (1-2) shows the causes of pipe failures and their contribution to the total number of failures in buried pipelines. The corrosion has significant influence on the failure of buried pipelines followed by ground movement and pressure transient [5].

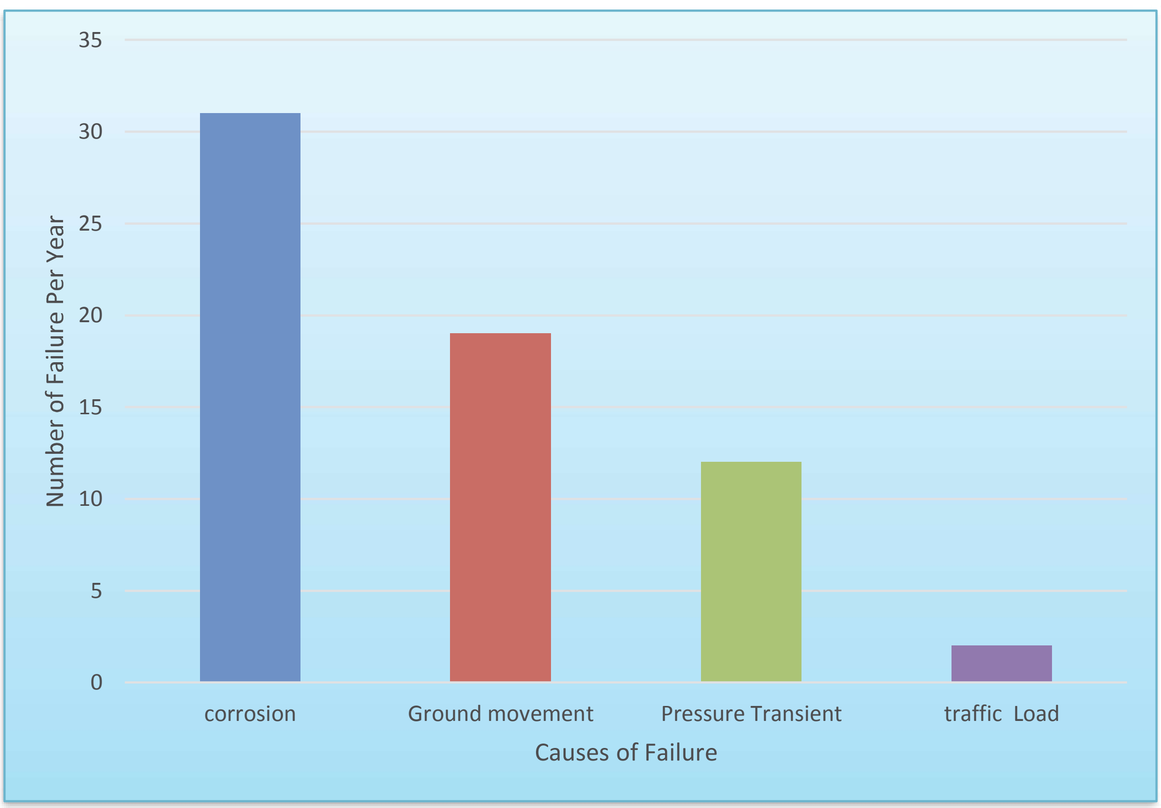

Figure (1-2): Causes of failures in buried pipe [5].

1.2 Literature Survey

Many studies have been carried out in recent years on polymer composites. These studies dealt with several important aspects pertaining to the composite materials, such as mechanical and physical properties.

1.2.1 Polysulfide Rubber and Resole Resin Additions Effect at Epoxy Resin

In (2001), Puglia et al, Reported the influence of the addition of various Epoxy resins on the thermal stability of Phenolic Resoles. Blends of phenolic resins with various compositions of Epoxy resins, cured with amine hardener, were characterized by thermal gravimetric analysis to determine their thermal stability and heat resistance. The results demonstrated that the Epoxy-amine content must be kept down 15wt% to avoid a significant drop of the thermal stability of the blend. However, blending with Epoxy-amines was a suitable road to improve the mechanical properties of phenolic resole resins [6].

In (2010) H Ku et al, Investigated mechanical properties of Epoxy resin and Resole resin blend mixed with Linseed oil in different weight percentages. Composite 40/60 means the proportion by weight of Epoxy resin is 40 percent. It was found that only composites 50 /50 and 40 /60 could be cured in ambient conditions. The result of dynamic mechanical analysis showed that only these two composites form interpenetrating polymer network. The addition of linseed oil to the two blends results also in the formation of interpenetrating network irrespective of proportion by weight of the resins. The mechanical properties will only be better when the percentage by weight of Epoxy resin is higher [7].

In (2014), Ekhlas E. Kader, Investigated the effect of addition polysulfide rubber with (2%, 4%, 6%, 8%, and 10 %) weight fraction on the mechanical and physical properties of Epoxy matrix. The results showed that the increase in polysulfide percentage increased the elongation, impact resistance, and flexural strength while decreased the tensile strength, modulus of elasticity, hardness, and wear rate. The results confirmed that the addition of 4% of polysulfide provided highest value of flexural strength, while the percentage 10% of polysulfide provided highest impact and hardness [8].

In (2016), Ryam E. Hawy, Studied mechanical properties of three types of blends (Epoxy(EP) + Polysulfide rubber(PS)), (Epoxy(Ep)+unsaturated polyester(UPE)) and (Ep + Ps + UPE). The results showed that all blends lead to homogeneous matrix with improved toughness properties and both types of polymers added to the Epoxy lead to reduce its brittleness. The results also showed that the increase in impact resistance of (Ep (80 %) + PS (20 %)) is (102.9%), for (EP (80 %) + UPE (20 %)) is (47.47%) and for (EP (80 %) + PS (10 %) + UPE (10 %)) is (3.84%). The highest value of the young's modulus was (816MPa) for pure Epoxy and the highest value of the flexural strength is (297MPa) to a sample of the triangular mixture and the best value of the compressive strength is (102.18%) to a sample of the mixture (Ep + UPE) and the best value of hardness is (21.1) to the sample of (UPE) [9].

1.2.2 The Effect of the Reinforcement Materials on the Mechanical and Physical Properties of Composite Materials

In (1982), E.P. Chang et al, Studied the mechanical and thermal properties of two types of reinforced resins (Epoxy, Resole) and compare the result separately. Carbon fiber has been used once with weight percentage (35-50%) and (glass and carbon fiber) were used in successive layers again. The results showed that phenolic composites possess mechanical properties similar to Epoxy composite properties and Epoxy composite have less thermal stability than phenolic composites [10].

In (2002), Najlaa, Prepared two different kinds of binary blends consist of (Epoxy / Polysulfide rubber), (Unsaturated polyester resin UPE/ Polysulfide rubber PSR) for the weight ratios (0 -100) %, and studied the mechanical properties (impact, tensile, flexural strength), then reinforced them with fiber glass and studied the same mechanical properties. It was discovered the mechanical properties of composites with matrix blended have larger than those of the composite with the single polymer matrix [11].

In (2003), Patel et al, Investigated the usage of acidic agents for several types of phenols (Phenol, P-cresol, P-tertbuty-Phenol) with formaldehyde for the preparation of resin (Epoxy- novolac phenol) and glass fiber was used for reinforcement. The result showed that the mechanical properties (tensile strength, impact strength, flexural strength) of Epoxy improved after merging with the novolac [12].

In (2008), Almusaui et al, Compared mechanical properties (impact strength, tensile strength and hardness) of phenolic formaldehyde resin before and after the reinforcement with kevlar fibers which were used with different weight ratios (20 - 60%). The result showed an increase in the mechanical properties of phenolic formaldehyde resins after reinforcement by fiber [13].

In (2013), Orhan S. Abdullah, Investigated the mechanical and physical properties of hybrid composite material made of Epoxy resin reinforced by different volume percentages (2.5%, 5%, 7.5%, 10%, 12.5%, 15%) of short fiber (glass and carbon) and different types of particles (Granite, Perlite, $CaCo_3$) in different volume percentages (1%, 2.5%, 4%, 5%). It was observed that most mechanical properties of hybrid composites increased with the increase of reinforcements content, such as compression strength, modulus of elasticity, and impact strength. The best hybrid composite was obtained when reinforcing Epoxy with 15% carbon fiber + 5% granite particles [14].

In (2015), Adnan N. Abood et al, Investigated the mechanical properties of the blend (Epoxy and Polysulfide rubber (0, 3%, 6%, 9%,15% and 25%) and reinforced the blend with two types of fibers (carbon fiber and polypropylene fiber) with different volume friction (10 %, 20 % and 30 %). The results showed that compressive strength and hardness were decreases when the polysulfide ratio increases while impact resistance and elongation were increases when polysulfide increases till 9% and the highest compressive strength and impact strength for the mixture which reinforced by 20 % carbon and 30 % polypropylene [15].

In (2016), Mustafa Z. Shamukh, Studied the mechanical properties for the blend of Epoxy and Polysulfide rubber with different weight (2.5%,5%,7.5% and 10%) from Epoxy and selected the percentage of 5% polysulfide as the best ratio, the results showed that the blend of (Epoxy- 5%Polysulfideerubber) gave an increase in impact resistance and damping ratio but decrease in compressive resistance, young's modulus and hardness compared with Epoxy only, and when the blend was reinforced with short carbon and glass fibers the results showed an increase in compressive strength, hardness, impact resistance and flexural strength. The composites of carbon and glass also were reinforced by red mud and fly ash Nano-particles addition, the results showed an increase in compressive resistance, young's modulus and impact resistance but a decrease in flexural strength and damping ratio [16].

1.2.3 Composite Pipes failure

In (1978), Spencer B. and Hull D., Examined failure of glass reinforced thermosetting pipes with four winding patterns of ±35˚, ±45˚, ±65˚ and ±75˚ with internal diameter of 50 mm. Subjected to internal pressure, experimental observations implied on this fact that both deformation and failure mechanism strongly rely on winding angles [17].

In (1984), Rosenow, Tested glass reinforced thermosetting pipes down biaxial pressure loading, hoop pressure loading and tensile loading. Six winding angles as 15˚,30 ˚, 45˚, 60 ˚,75˚and 85˚were used to fabricate samples with diameter of 50.8 mm for investigational study. Strain gauge is used to measure the axial and hoop strains. The obtained results from investigational observations have been compared with classical lamination theory (CLT) and good agreement has been reported. It was cleared that best winding angle for biaxial pressure loading is 54.75˚ while it is 75˚ for hoop pressure loading [18].

In (1996), Doyum AB. and Altay B., Investigated the failure of thin filament wound fiber reinforced thermosetting pipes exposed to drop test. The samples have been fabricated using E-glass and S-glass fibers with [±54˚/90 ˚] and [±45˚/90 ˚] winding pattern, respectively. Dissimilar energy levels varying from 3.5 to 8.5 J have been applied to the samples and it was detected that most E-glass tubes experienced surface cracks and delamination [19].

In (2007), Trickey S. and Moore I., Performed a numerical analysis for pipes with varying stiffness and depth underground. It was found that the burial depth had little impact on the peak deformation for stiff (rigid) pipes located close to the ground surface. however, for flexible pipe, the peak deformation decreased significantly as depth increased [20].

In (2012), Deniz ME. et al, Experimentally estimated the influence of tube diameters and impact energy on the compressive strengths of GRE pipes. Dissimilar samples with various diameters of 50,75,100 and 150 mm fabricated with winding pattern of [±55˚] were firstly exposed to three various energy levels in impact tests. Then, the axial compressions of impacted and non-impacted samples have been measured. It was create that both impact energy and tube diameter severely affect the post-impact strength and impact response [21].

In (2013), Robert D. and Soga K., Calculated the effect of unsaturated sandy soils on pipeline by using a finite element analysis. The results exhibited that the characterization of soil as an unsaturated state is required for pipeline problems to occur. Results also exhibited that an increase in moisture content lead to in an increase in soil loading on the pipeline [22].

In (2014), Nimish K. et al, Calculated stress analysis of underground GRP pipe exposed to internal and external loading conditions. Where Epoxy was used as a matrix material and glass fiber (E-glass, S-glass) as a reinforcement material. The stress analysis of steel pipes is performed using ANSYS, which was followed by a comparative study of steel and GRP pipes because GRP material consists of several layers, the analysis of stresses developed in its complicated. The result showed that the present design of the GRP pipe cannot withstand the pressure applied. Hence the present design of the GRP pipe has to be changed [23].

In (2015), Xing J. et al, Calculated deformation and stresses of a thick filament wound composite cylinder with multi-angle winding pattern exposed to combined loading consisting of axial loading and both internal and external pressures. In-plane stress components in on-axis coordinate systems were analytically found for each layer. The results of Finite Element analysis were in a very good agreement with theoretical modelling results. It was found that by increasing wall thickness–radius ratio, 3-D stress state could show and thus stresses on the outer and inner surface is different showing the importance of taking into account wall thickness in thick walled structures [24].

In (2015), Srebrenkoska V. et al, Investigated the hoop tensile properties of continuous fibers reinforce composites pipes. The test pipes were manufactured of fibers and Epoxy resin by filament winding method with three various winding angle configurations (10 °, 45° and 90 °). They determined that, mechanical properties of composite samples are dependent on winding angles in filament winding technology. The larger winding angle lead to higher hoop tensile properties of filament-wound tubular spacemen. The best values for the hoop tensile strength are found for the spacemen winded with 45° winding angle and best values in tensile strength and break force were found from composite pipes winding with angle 90 °[1].

In (2015), Long Bin Tan et al, Studied analysis of buried composite pipe, two cases are presented to study the buried pipe response, in terms of the induced hoop and axial stresses and the resulting pipe displacement, due to overburden load. The effect of internal pressurization of the pipe is also investigated. Other parameter such as the resulting soil stresses is also analyzed. The simulation results provided insights to the response of buried composite pipes and in particular the pipe-soil interaction that occurs for mutual transfer of loads between the soil and the pipe. Results revealed that internal pressurization reduces pipe ovalization due to overburden loads but tended to increase pipe axial stresses at pipe bends [25].

In (2016), Rafiee et al, Used FE modeling to know the variations of stress components in an industrial polymers composites pipes. They have presumed that fiber volume fraction varies between 50 %and 60 % and winding angle of cross layers complies with 60˚±1.5˚. Results displayed that the influence of winding angle differences, even for very small values, is much more pronounced than the fluctuation of fiber volume fraction [26].

In (2016), B. Sairam Goud et al, Studied an analysis of composite buried pipe. Structural analysis of pipe is done in ANSYS software. Buried pipe was studied for structural analysis for internal pressure load for steel material and two composite materials (E-glass/ Epoxy and Carbon/ Epoxy materials) with different layer orientation. From analysis, it is concluded that E-glass/Epoxy material is alternative material for buried pipe because it has von mises stress less than the yield stress of the material [5].

In (2016), İsmail Yasin Sülü, Investigated the stress analysis of multi-layered hybrid composite pipe with symmetrical orientation angles, under internal pressure. The codes of numerical models were created in ANSYS software for numerical analyses. Two inner surfaces of the first model are E-glass fiber/Epoxy and its two outer surfaces are carbon/epoxy. Inner surfaces of second model are carbon/Epoxy and its outer surfaces are E-glass fiber/Epoxy. Several orientation angles as (45/-45/-45/45), (55/-55/-55/55), (60 /-60 /-60 /60) and (75/-75/-75/75) were used. The result showed that the stresses of [45˚/-45˚] for both material orientations are the greatest from the inner surface to the outer surface of the pipes than other. Moreover, stress of the model, inner surfaces carbon/Epoxy and outer surfaces E-glass fiber/ Epoxy, is the greatest [27].

1.3 Aims of Present Work

1- Preparing two types of binary blends of Epoxy resin with different percentages of Resole resin and Epoxy resin with different percentages of

Polysulfide rubber, and assessing the mechanical properties of both two type of blends, in order to determine the best blend matrix.

2- Preparing hybrid composites of carbon and glass fibers with Epoxy-Resole blend and with Epoxy- Polysulfide blend, and exploring the effect of hybrid fibers on the mechanical properties, such tensile strength, modulus of elasticity, hardness, impact strength, flexural strength and wear, in order to determine the best hybrid composite.
3- investigating the absorption ability of all prepared composites.
4- Examing mechanical, physical and morphological properties to ensure the proposed composite and hybrid composite is valid in pipeline industries.
5- Identifying a new class of functional polymer composites suitable for pipelines. pipelines usually made from steel, this material is usually expensive. In this study, used the composite materials to prepare the required material by using widely available cheap materials with good mechanical properties.

1.4 Thesis Outline

The thesis contains five chapters are:

- Chapter one includes general introduction and the literature survey.
- Chapter two includes theoretical part about composite materials and it constituents.
- Chapter three includes the experimental work by giving details about materials used, reinforcement materials, composites preparation and technical testing procedures.
- Chapter four includes results and discussion of the experimental work of the composite samples and numerical analysis for all types of composites.
- Chapter five includes the conclusions and recommended for future works.