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Effect of Ply Angle on the Burst pressure of Composite Pressure Vessels by Filament Winding

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Abstract
Composite pressure vessel is important structure in different application include pipe and pipe under pressure , the closed system pipe under high pressure and temperature such as gas pipe line and aircraft structure . because of the characteristics of polymer – composite as alternative of heavy materials as metal of various application. The current work focus on the study of strength phase orientation and there properties on the burst pressure strength and other parameter ,which are very important in design and manufacture of these vessel such as selection of type of strength phase nylon 6,6 and philosophy of mixing of there type of fiber with matrix material (epoxy). The work also include the study the effect the two layer angle ply [0/90],[55/-55],[75/-75] and implementation the different material testing to evaluate the toughness and stiffness of these vessel and compare the experimental result with theoretical result. The filament winding apparatus was designed and executed to manufacturing of different type patron according to these angle of ply nylon fiber the mechanical tensile test ,drop test ,pipe stiffness test ,hydrostatic pressure test are use to test these vessel . The results shown that ply orientation [75/-75] have high tensile properties , high toughness, high stiffness result , high impact result , high burst pressure result than other ply orientation . so that [75/-75] ply orientation is optimal angle of vessel. Tensile test shown that [75/-75] ply orientation sample have higher properties in two direction longitudinal and transverse direction than other samples.

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1.Introduction of composite pressure vessels

Composite materials typically provide a high possibility of producing of construction that include a stimulating mechanical performance, mainly with respect to specific stiffness, specific strength, damage tolerance, and energy absorption capability. Composite pressure vessels are a perfect example of the benefits that fiber-reinforced composite materials can give.They can be created from strong fibers in combination with a resin or plastic. The method for manufacturing the composite pressure vessel is called filament winding. Composite pressure vessels were initially developed for aerospace applications(1) .composite pressure vessels realize application in numerous fields

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varied from households to professional to aviation. They are critical component in numerous systems as their failure can lead to fatal accidents due to pressure differential. One amongst the necessary parameter to be calculated during design is burst pressure. Bust pressure is that the pressure at that vessel burst open /crack and internal liquid leak. It is a design safety limit that should not go over . If the pressure is exceed it may lead to mechanical breach and everlasting loss of pressure containment (2).Pressure vessels are created by filament winding for a long period. Although they seem to be easy structures, pressure vessels are one of the most difficult to design. Filament-wound composite pressure vessels have found widespread use not only for military use however conjointly for civilian applications. This type of technology initially developed for the militaryuse was adapted to civilian purpose and later extended to the industrial market. Applications include breathing device, such as self-contained breathing apparatuses used fire-fighters and alternative imperative personnel, scuba tanks for divers, oxygen cylinders for medical and aviation cylinders for emergency slide pumping, opening doors or lowering of landing gear, mountaineering expedition equipment, paintball gas cylinders, etc. “(3)

2Filament Winding

Filament winding is a general production technique for composite structures. In the filament winding process, a fiber bundle is placed on a rotating and removable mandrel. Consequently, it is mostly applied to manufacture axisymmetric structures. Continuous filaments are an inexpensive and excellent form of fiber reinforcement and can be oriented to match the direction of stress loaded in a structure. Fuel tanks, oxidizer tanks, motor cases and pipes are some examples of filament wound axisymmetric structures under internal pressure(6).Fiber from continuous-fiber roving gets wetted as it permits through a resin bath . This resin-wet as it exits from resin bath gets wound on a mandrel, which continually rotates on its axis of symmetry. Care is taken, that there is adequate tension in fiber so that the winding remains taut on the mandrel. Remains taut on the mandrel. Using such an approach, the filament winding pattern can helical, or circumferential, or even longitudinal. Quite often, an optimally designed filament wound part would have a combination of winding patterns. (5)

3PROCESS TECHNOLOGY

Filament winding is a fabrication technique for generating structures using fiber-reinforced plastics (FRP, or composite materials). The process involves winding filaments under tension over a male mold or mandrel. In the most humble form of winding, the mandrel rotates on a spindle around a horizontal axis, while a carriage moves backwards and forwards horizontally, laying down fibers in the desired pattern. The most common filaments are carbon fiber, glass fiber and aramid fiber (eg 'Kevlar'). These fibers are coated (impregnated) with a liquid synthetic resin just before they are wound in the process known in the composites industry as 'wet-winding'. However, it is also possible to filament wind fibers which have been 'pre-impregnated' with a solid, but flexible resin that hardens only when exposed to heat. Once the mandrel is completely covered to the desired thickness, the mandrel might be placed in an oven to solidify (cure) the resin. Though, with many resin systems it is also possible to conduct room-temperature cure cures. After curing product is removed from the mandrel either by hydraulic or mechanical extractor. (7) .figure1.1shown the filament winding technology.

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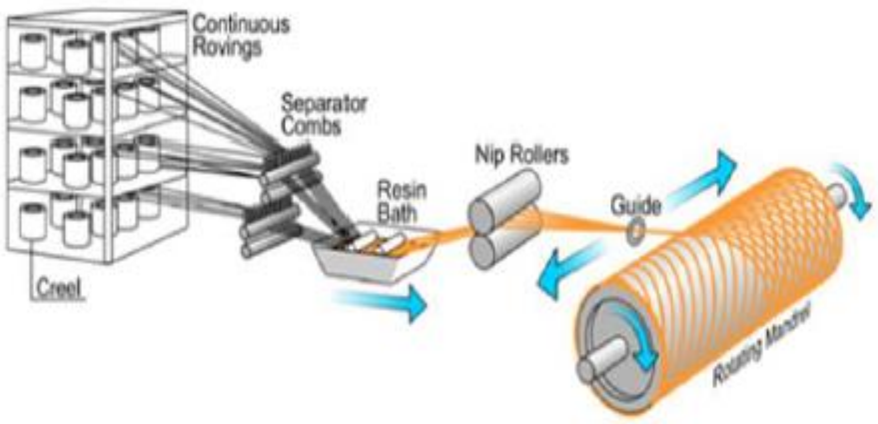

Figure (1.1):Schematic presentation of the filament winding technology (7)

4 Experimental Part

Material

Nylon 6,6 fiber

Nylon 6,6 is the most common commercial grade of nylon. The nylon 6,6 fiber reinforced composite material have high tensile strength , high elongation , Excellent abrasion resistance Highly resilient (nylon fabrics are heat-set), Used in many military applications. Mechanical properties of fiber were measured experimentally by tensile test machine as shown in figure (1.2), the mechanical properties of fiber given in the table 1.1.

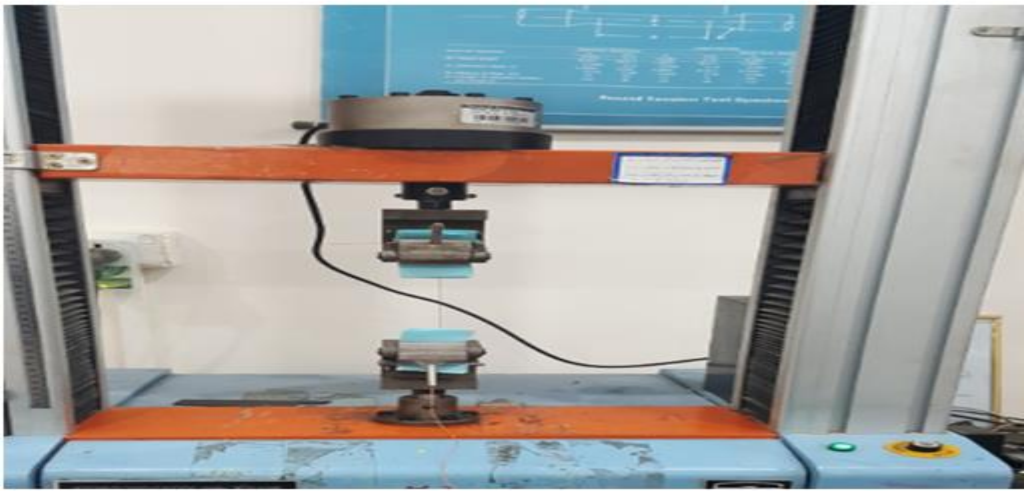

Figure (1.1): Fiber Tensile Machine

Table (3.1) : Mechanical properties of fiber

Property	Unit	Nylon6,6fiber
Elastic modulus	MPA	1340
Tensile strength	MPA	570
Max .Tensile stress	MPA	565

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Matrix

The epoxy resin gives a superior adhesion pro the fiber reinforcing. It was utilized slkadur 52 LP contains : reaction product bispenol A (eplchlorohydrin) oxirane , momo {(c-12-14alkyloxy) methyl } derives.. The hardener material was used slkadur 52 LP Anhydride. The mechanical properties of matrix were measured experimentally by tensile test according to ASTMD D3039 standard; the mechanical properties are listed in the table (1.2).

Property	Unit	Epoxy resin
Elastic modulus	MPA	11030
Tensile strength	MPA	3
Max. Tensile stress	MPA	2.75

3 Sample preparation to Production of Composite Pressure Vessels

- NRP(nylon reinforce polymer) pipes are manufacturing with several winding angle by using filament winding machine(tearing machine) [(0,90),(55,-55),(75,-75)] .
- The flexible Al pipe mandrel is fixed between two jaws .the flexible Al pipe helps to tying and untying aluminum pipe before and after winding , the system winding as shown in figure(1.2).

Figure (1.2): system winding

- Resins are mix with hardener for 4-5 minutes results appropriate viscosity.
- The angle winding of fibers is delimit by protractor above the mandrel and the fibers are wound above the mandrel as shown from the figure (1.3).

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Figure (1.3): Delimit angle and winding fiber

- The resin are add on the fiber above the mandrel (Pre-impregnate winding) as shown in figure(1.4).

Figure (1.4): resin add in external mold

- The sample was then allowed to cure are cure for 24hours at room temperature .Two layers of reinforced provides 3.2 mm thickness. The test specimen length equal to 300mm and internal diameter was 43mm as shown in figure(1.5).

Figure (1.5): production of pressure vessels

The weight of fiber in pipe sample before and after add resin and volume friction of fiber by weight as shown in the table (1.3)

Table (1.3) : weight of fiber in pipe sample before and after add resin and volume friction of fiber by weight

The angle of fiber	Wight of fiber before add(gram)	Wight of fiber after add(gram)	Volume friction of fiber(gram)
55	30.56	150.56	20.3%
75	70.75	190.75	37.2%
90	63.75	183.75	34.6%

4 Production of composite sheet:

Composite sheet was prepare by the film stacking method . It consists of the following steps:

- firstly the wax was add in the mold to help release the product from the mold as shown in the figure (1.6),by use square wood mold dimension 28×28cm, and glass frame with thickness 2 mm was fixed around the mold.
- Two layer fibers were arranged in the suitable angle, and these fibers layer fixed by the nails on the wood mold .
- Resin and hardener are mixed together for 4-5 minutes .After that the resin were applied to every layer by using the brush.
- The mold were placed inside the electrical oven at 100 c˚ for 30 min get a required thickness. The composite sheet are release be remove the nails and mold.
- The procedure of this process make two layer of composite sheets of different types [0,90],[55,-55],[75,-75] as shown in figure (1.7).

Figure (1.6): wax add on the wood mold

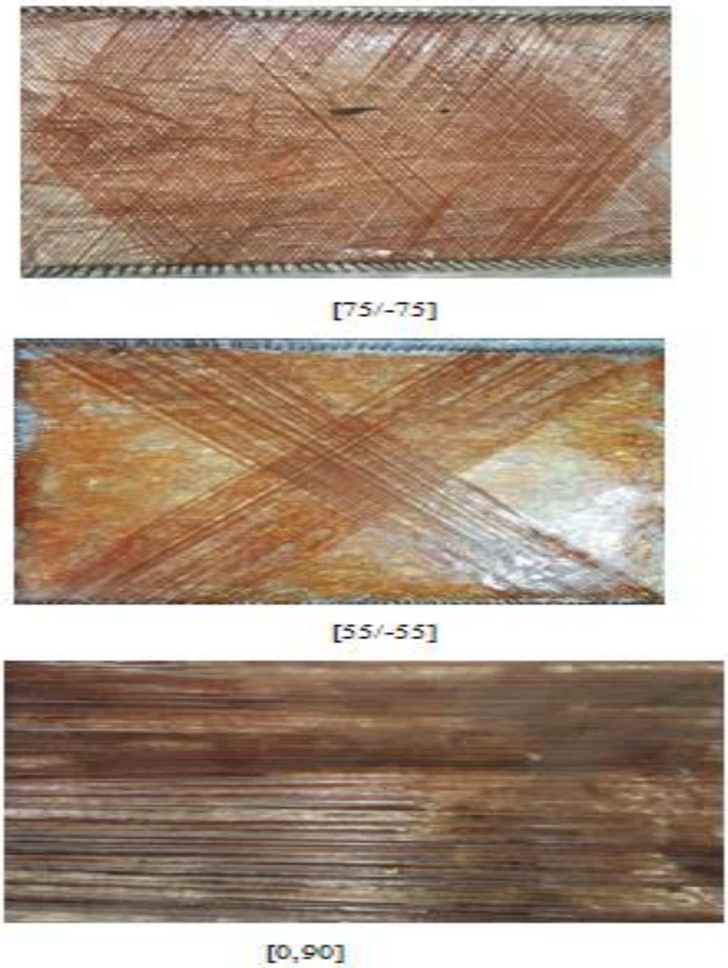

Figure (1.7) : Different Composite sheet Winding Angle

Table (1.4) , (1.5),(1.6)shown calculation weight ratio of fiber and resin in every sample.

Table (1.4): calculation weight ratio of fiber and resin with angle 55 degree.

Angle of sample	Weight of fiber (gram)	Weight of resin (gram)	Thickness of composite sheets (mm)
55 degree	7	240	2

1)Volume of composite =28×28×0.2=156.8cc

2)Wight of resin= 120×2=240g

Table (1.5): calculation weight ratio of fiber and resin with angle 75degree

Angle of sample	Weight of fiber (gram)	Weight of resin (gram)	Thickness of composite sheets (mm)
75 degree	8.769	240	2

1) volume of composite=28×28×0.2=156.8cc

2) weight of resin=120×2=240g

Table (1.6): calculation weight ratio of fiber and resin with angle 90degree

Angle of sample	Weight of fiber	Weight of resin (gram)	Thickness of composite sheets (mm)
90 degree	11.692	240	2

1) volume of composite=28×28×0.2=156.8 cc

2) weight of resin=120×2= 240 gram

Tensile Test

Tensile testing of composite material according to ASTMD D3039, the sample length = 250mm and width of sample = 25 mm is used to determine mechanical property data. Uniaxial tensile force is applied to a flat test specimen to investigate the stress/strain behavior, load / deformation and critical materials properties including tensile modulus in the axial and hoop direction, tensile strength, elongation at break. Six samples are used were two samples from every sheet of composite material in two direction.A highly precise Universal testing device is consists of a constant frame that made for compression testing or tension.

The max load ability of the frame has 100 KN and by it can operate the moving crosshead by two ball screws that were vertical at a system of a drive with positional electronic hold servo technique.the determination of mechanical properties, in particular the elastic moduli and tensile strengths of the anisotropic

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material, is more challenging. So that the sheet manufactured to simulate pipe design . The sheet samples are cutting according to pipe direction sample axial and hoop direction as seen in figure(1.8),(1.9).

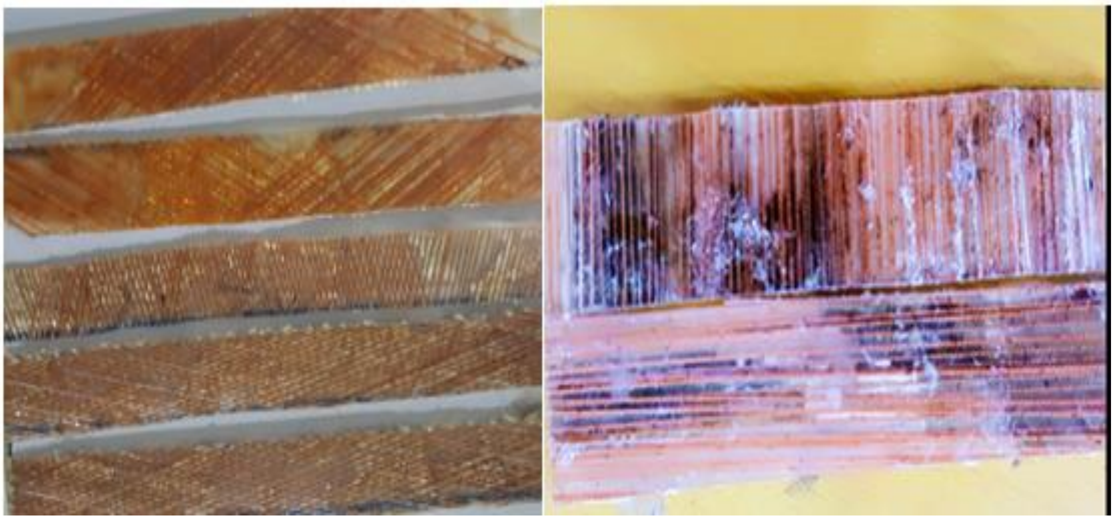

Figure (1.8) : tensile test sample

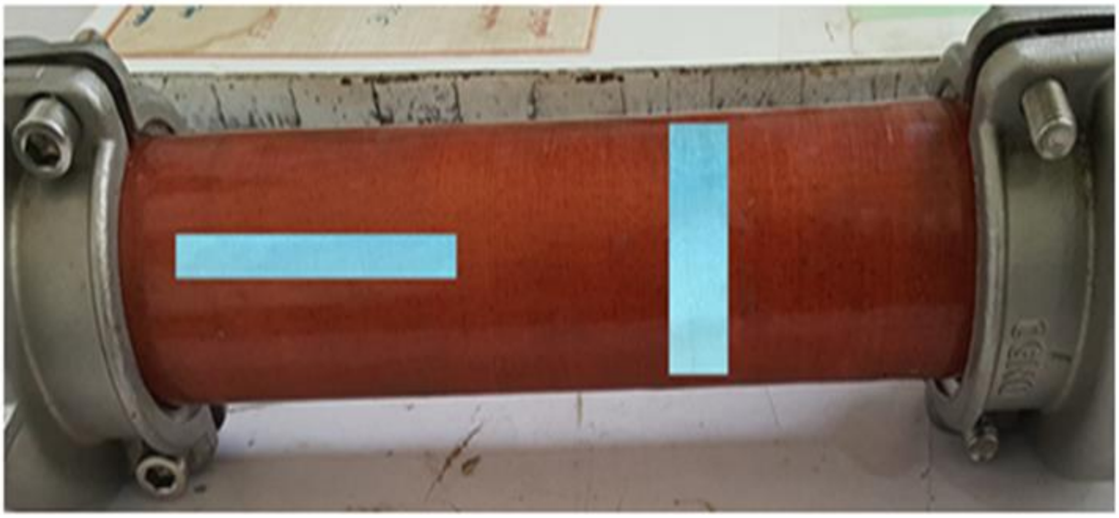

Figure (1.9): pipe sample direction

5 Burst pressure test

The interior pressure is useful by a micro-processor controlled 100 bar by XGY – pipe hydrostatic testing machine. The method accounts the variant in interior pressure by time through the test, until the specimen fractures, and so the bursting pressure. The determining process for burst pressure of pressure vessel of composite is depends on **ISO 1167, ASTM D-1598** standard. Computer control model, high intelligence, real-time monitor, auto-recorder pressure force, and time are easy to operate and reliable. The pressure test system is shown in figure 1.10.

Figure (1.10):Specimen instrument matching

Mechanical properties result

Tensile Result and discussion

Tensile test result: In the figure 1.11, 1.12 which is shown the relationship between the load and deformation and stress – strain relationship for anisotropic plate is manufactured to simulate pipe design layer . The result of tensile test in the figurers present the axial direction. It is very clear from the figures 4.1 the relation between load – deformation is linear from the all samples preparation series (1,2,3) and that belong to the applied load not exceed the elastic deformation and there are not plastic deformation in the nylon reinforce polymer pipes , and that very important for the stability of the dimension of the pipes, and for the comparison between the series (1,2,3), it is very clear that the series (2) is highly elastic deformation and has the good load strength, high elastic modulus ,and that mean that series (2) is high strength from side and very tough from other side, because increasing the elastic energy under the of series (2), . The mix behaviors which is together is toughness and strength in series (2) is due to effecting of the reinforce polymer in these dimension .So that in transverse direction the nylon reinforced polymer exhibit average tensile strength values for 30 MPa for ply orientation ±75 (series 2) grater when compare with ±55(series3)is found to be 7 MPa is grater similarly when compare with (0,90)ply orientation(seies1) is 3 MPa. With increasing the angle configuration (helical angle) in axial direction the tensile properties increase. The tensile modulus value for 76744 MPa for ply orientation ±75 (series2)grater when compare with ±55 (seies3) is found to be 34560 MPa is grater similarly when compare with 90 (series1)play orientation is 11030 MPa..

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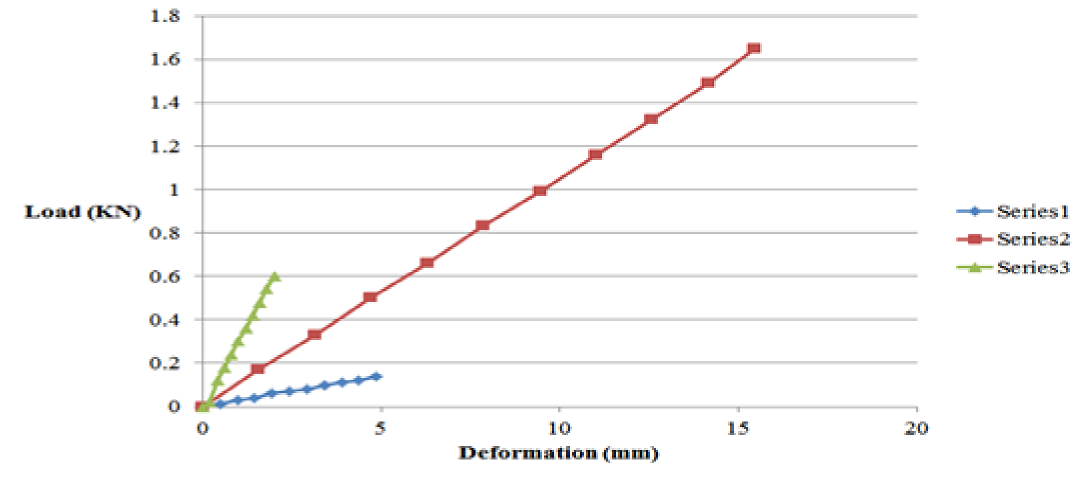
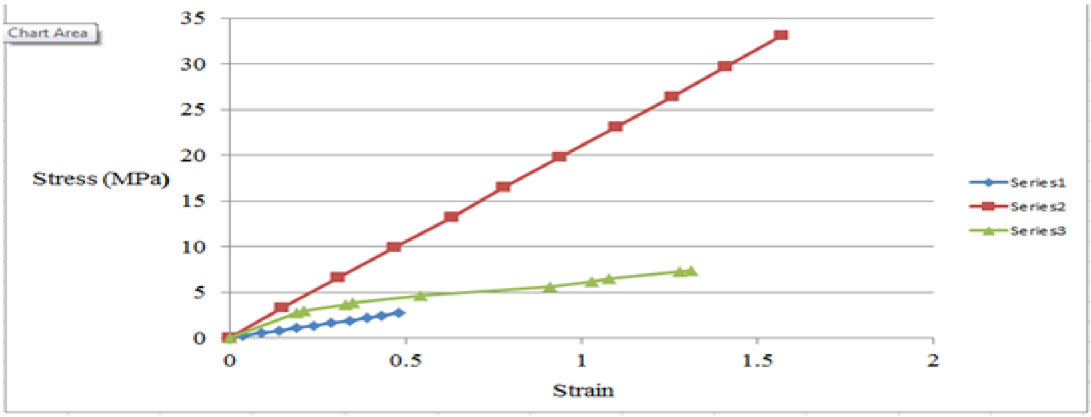


Figure (1.11): Load – deformation of NRP in axial direction. Where : Series1 is load deformation of 0 play orientation.Series2 is load deformation of ± 75 play orientation.Series3 is load deformation of ±55 play orientation



Figure(1.12) : Stress – strain of NRP in axial direction . Where : Series1 is stress – strain in 90 ply orientation. Series 2 is stress – strain in ± 75 ply orientation. Series3 is stress – strain in ± 55 ply orientation.

From figure 1.13 , 1.14 which is shown the relation between the load – deformation and stress – strain in hoop direction of sheet which is simulated the pipe design , it is very clear that the relation behavior is linear and there is no plastic deformation in this dimension , and these behavior is very important for stability of pipes dimension in this direction . where that case because of brittle fracture (rigid pipe) for all the design samples of pipe. But the deformation in series(1) is greater than other series (series(2),series(3)) . and the strength increasing in series 1 in the hoop direction ,because of effect of the fiber strength in the direction of applied load according to the rule of mixture : $E1= E f_{\varphi} +(1-_{\varphi}) E m$ (3).But the stress – strain and elastic moduls behavior remain that behavior and observe the litle change in series (1)is grater than series (2)and remain series (3) higher than other sieries, because the effect of orintaed area , and length of sample. So that in hoop direction the tensile strength values become 4 MPa for ±75 play orientation lower than when compare with ±55 is found to be 5 MPa similarly lower when compare with 90 is found to be 10 MPa. The tensile modulus values become 72558 MPa for ± 75 play orientation grater than when compare with ±55 is found to be 11520 MPa and this lower when compare with 90 is found to be 16564 MPa. Figure 2.1 ,2.2 shown load – deformation and stress – strain curves in hoop direction.

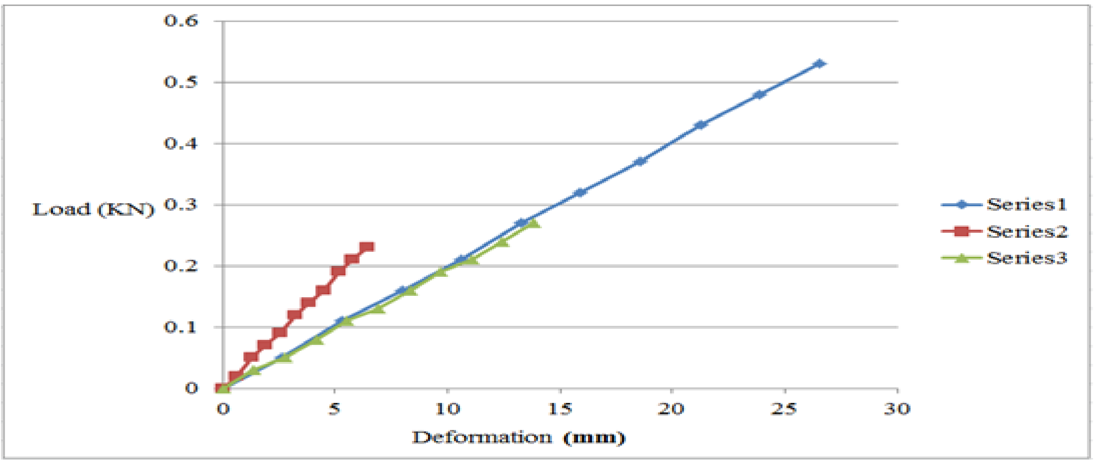


Figure (1.13) : load - deformation curves of NRP in hoop direction Where: series (1) is load – deformation curve of 90 play orientation. Series(2) is load – deformation curve of ± 75 play orientation .series (3) is load – deformation curve of ± 55 play orientation

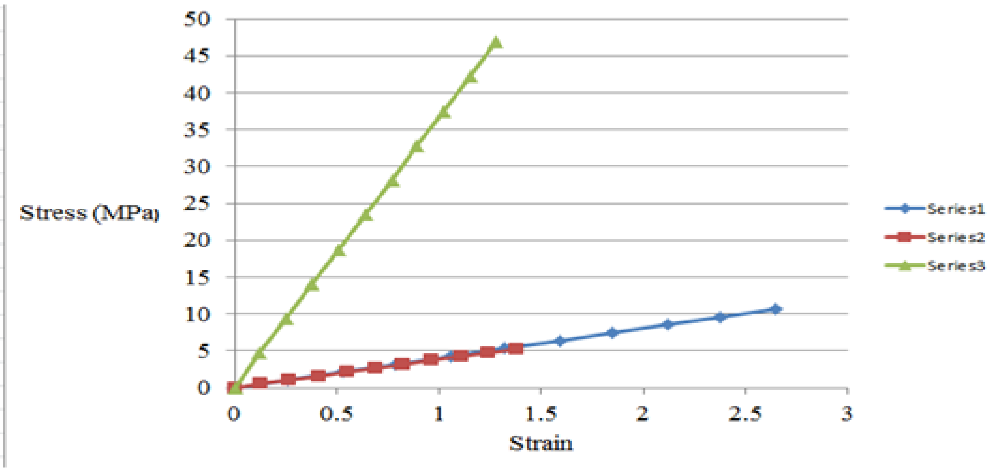


Figure (1.14): Stress – strain curves of NRP in hoop direction. Where :series (1) is stress – strain curve of 90 play orientation. Series(3)is stress – strain curve of ±75 play orientation. Series(2)is stress – strain curve of ± 55 play orientation.

Burst pressure result: Winding angle depend of burst pressure test tubes(Karpuz, M.S., and ANKARA 2005). In order to decide the optimum winding angle, the winding angle was chosen between 0˚ and 90˚(ÖNDER 2007) . Figures 1.15 , 5.16 , 1.17 shown the burst pressure curve with time of different ply orientation. Table (1.3) shown the burst pressure in bar unit with different pipes winding angle.

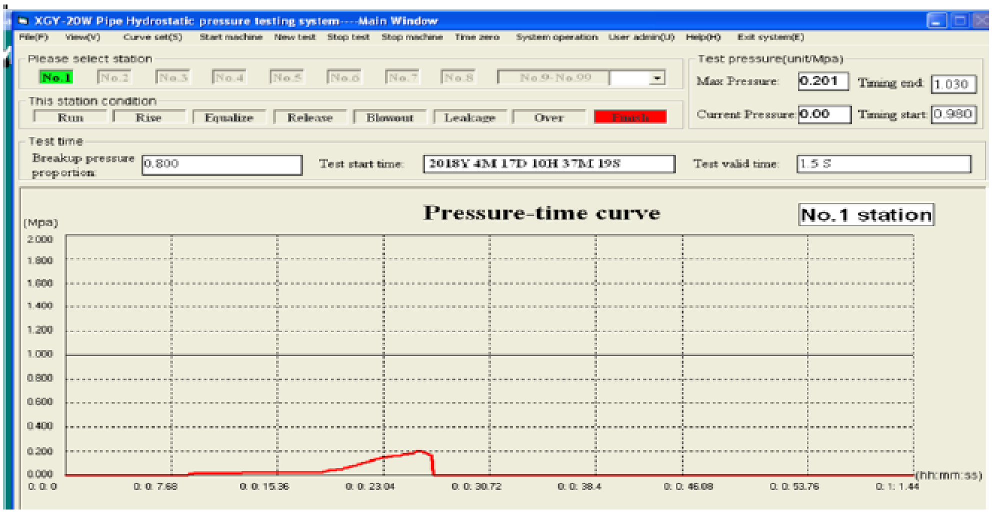


Figure (1.15): Burst pressure test(0, 90) ply orientation pipe

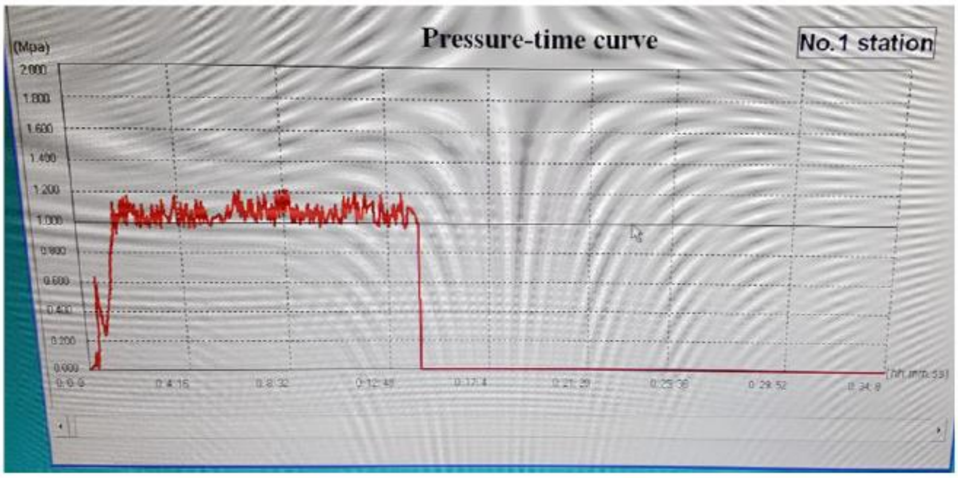


Figure (1.16):Burst pressure test of ±55 ply orientation

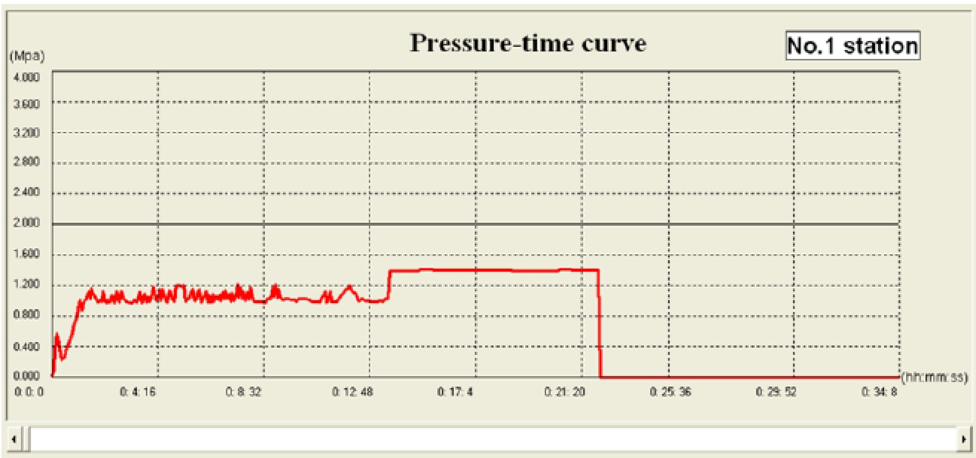


Figure (1.17): Burst pressure test of ± 75 ply orientation

Table (1.4) : Burst pressure test in (bars) unit

Winding angle (°)	Burst pressure (bar)
90/90	2
+55/-55	12
+75/-75	14

It can be observed from figures 2.3,2.4,2.5 that under internal pressure , the burst pressure increase with the increase angle configuration ,depend on tensile test result and burst pressure result observe that 75 ply orientation have high stress – strain in two direction and have high deformation and elastic modulus , high toughness and have high burst pressure is grater when compare with 55 ply orientation and similarly grater when compare with 90 ply orientation.

CONCLUSION

From experimental work shown is the ultimate burst pressure become higher when increase the winding angle because configuration when the filament angle increase the strength of composite vessels become higher . when the pressure vessels winding at hoop (0,90) angle the burst pressure become 2 bar , when the pressure vessels winding angle at 55 the burst pressure become 12bar ,and when the pressure vessels winding at 75 angle the burst pressure become 14 bar and have high tensile properties so the 75 ply orientation is the optimal angle.

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