

**Fabrication and characterization of Fiber Reinforced plastic pipe  
using contrived split mold**



**By**

**Bekele Yitayew Nigussie**

**A Thesis Submitted to Department of Mechanical Design and  
Manufacturing Engineering**

**School of Mechanical, Chemical and Materials Engineering**

**Office of Graduate Studies**

**ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY**

February, 2021

Adama, Ethiopia

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**Associate Professor**

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## Approval sheet

We, the undersigned, members of the board of examiners of the final open defense by Bekele Yitayew Nigussie have read and evaluated his thesis entitled “**Fabrication and characterization of Fiber Reinforced Plastic pipe using contrived split mold**” and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirement of the degree of Master of Science in Manufacturing Engineering.

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## Declaration

I hereby declare that the work which is being presented in this thesis entitled “**Fabrication and characterization of Fiber Reinforced Plastic pipe using contrived split mold**”. In partial fulfillment of the requirements for the award of the degree of Masters of Science in Manufacturing Engineering is an authentic record of my own work, has not been presented for a degree of any other universities, under the advising and supervisions of Dr. Perumalla Janaki Ramulu (Asso. Prof), Mechanical Design and Manufacturing Engineering Program, Adama Science and Technology University, Adama, Ethiopia.

The matter embodied in this thesis has spent one-year time duration to accomplish the whole work and all relevant resources of information used have been currently referred.

Bekele Yitayew Nigussie

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\_\_\_\_\_

Endorsed candidate

Signature

Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge and supervision. This research can be submitted for examination with my approval.

Dr. Perumalla Janaki Ramulu (Asso. Prof)

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## Abstract

Fiber reinforced plastics (FRP) play a vital role in many engineering applications as an alternative to various heavy exotic materials. Such composite pipes are finding applications not only in construction industries, but also in the transportation of corrosive fluid. In FRP pipe composites, the matrix of polymer (unsaturated polyester resin) is reinforced with glass fibers (chopped strand mat and woven roving) in form of cloth like sheet layers. These pipes are manufactured through hand lay-up processes using contrived split mold method. The reinforcement sheet of FRP pipes prepared each require pallet size by hand and its round uniformly to form pipe with mandrel shaft seated on the working table and then inserted through fixed split mold and clamped with bolt and nuts. The amount of resin puring in contrived mold and closed cup clamped with fasteners for uniform embodiment of composite it rotates on lathe machine by fixed between tail and head stock. The produced products of FRP pipe needed post curing of 24 hours to remove and demolded from contrived split mold. This thesis mainly focuses on the mechanical properties of compressive strength, hardness and water absorption of chopped strand mat and woven roving fabricated FRP pipe. An experimental has been studied on the compressive strength of FRP pipe increased as the number of layers increased. The seven round of woven roving FRP pipe has best compressive strength value of 19.04 N/mm<sup>2</sup> and chopped strand mat of seven round of FRP pipe has 15.93 N/mm<sup>2</sup>. The hardness test result of 7 round layers of PWR pipe has high dens than other FRP pipe with Vickers hardness value of 64.93HV. The water absorption test of the chopped strand mat has better than woven roving pipe due to higher amount of resin matrix required to perform the product.

**Keywords:** FRP pipe, mandrel, outer split mold, lathe machine and mechanical test.

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## Abbreviation and nomenclature

symbols	Description	Symbols	Description
FRP	Fiber Reinforced Plastic	$\rho_{ct}$	Density of composite
CSM	Copped Strand Mat	$\rho_f$	Density of fiber
PWR	Plain Woven Roving	$\rho_m$	Density of matrix
UP	Unsaturated Polyester	$V_v$	Void content
GRP	Glass Reinforced Plastic	Cm	Centimeter
ASTM	American Society for Testing and Methods	D	Diameter
L	Length of specimen	H	Hour
T	Thickness	HV	Vickers Hardness
$w_f$	Weight of fiber	ACT	Axial compression test
$w_m$	Weight of matrix	HCT	Hoop compression test
$V_f$	Volume of fiber	MPa	Mega Pascal
$V_m$	Volume of matrix	N	Newton
OPM	Optical microscope	mm	Millimeter
N	Newton	A	Area
MEKP	Methyl Ethyl Ketone Peroxide	F	Applied force for indentation
SFRC	Synthetic Fiber Reinforced Composite	UTM	Universal Testing Machine

# Chapter one

## Introduction

Fiber Reinforced Plastic is a composite material consisting of reinforcing fibers, thermosetting resins and other materials such as fillers and pigments may also be present and the synthetic fiber is generally used as a reinforcing material and resins are usually used as a binding agent [1]. The major application of FRP are consumer products such as chair trays, helmets, pipe ducts, water cooler body, water tanks paneling. Fiber-reinforced plastic (FRP) composites are meeting an increasing demand as construction material due to their excellent properties including light weight, high specific strength, corrosion resistance, and low maintenance cost [2]. Fiber reinforcing plastic pipes are attractive physical and mechanical properties, particularly their strength to weight ratio and resistance to fatigue and corrosion and other features such as ease of installation, high durability and low maintenance and life cycle costs make them more desirable than conventional materials such as steel. In addition, due to their anisotropic nature, FRPs can be tailored to specific applications to achieve the highest levels of performance required [3, 4].

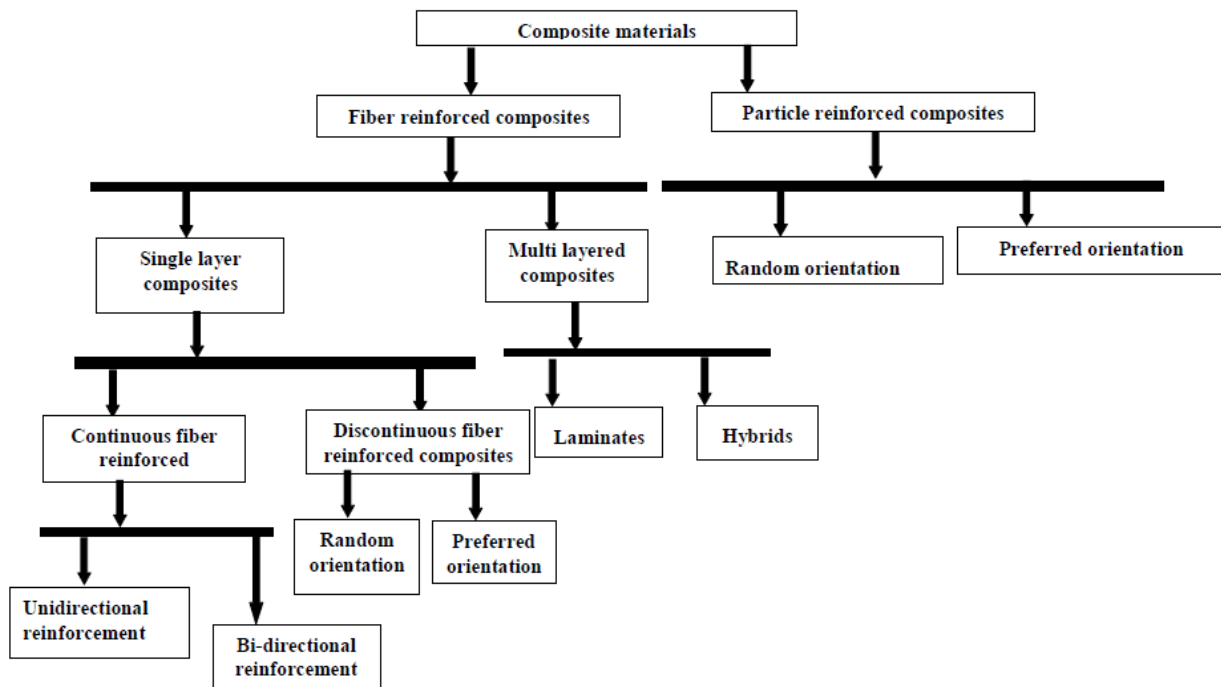


Figure 1.1 Classification of composite [3]

Composite material's good corrosion resistance, durability and high strength-to-weight ratio, the use of FRP pipes has increased in many diverse industries such as, offshore marine, chemical processing and pressure piping [5]. However, these materials are susceptible to degradation in mechanical performance, reduction of structural integrity and fluid leakage due to incidental low velocity impacts, either in service or during handling. FRP pipes 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 and diameters of pipe produced range from 25mm to 2000mm currently [6]. As mentioned, the primary reason to employ fiberglass tubulars are their resistance to corrosion when compared to carbon steel counterparts. This is especially significant when down hole tubulars, storage flow lines and surface facilities are interacting with, storing and transporting corrosive substances. These include, but are not limited to corrosive formation fluids, produced water, sulfur compounds (sour gas and oil), bacterial oxidants and mineral ions within any number of solutions. The large number of corrosive agents is the underlying cause behind corrosion becoming one of the most extensive and expensive problems in the oil and gas industry [7]. Corrosion renders the steel tubulars to fail, unable to withstand their respectively rated burst and collapse pressure ratings. Replacement of the metal equipment or assembly is then required to avoid failures, accidents, or losses in production/profit [8]. A large number of operators employ fiberglass tubulars to mitigate corrosion control costs. Aside from the obvious cost-savings, secondary corrosion-related costs are also completely removed from project scopes such as corrosion-inhibitor injection, pig runs, and standby replacement piping. The additional advantages of fiberglass like easier handling, transport and installation outweigh the disadvantages and uncertainties associated with these tubulars, some of which will be addressed in this paper.

## **1.1 Background of study**

Ancient Jewish slaves used straw to enhance the structural integrity of the bricks they molded for the Pharaohs. The Egyptians wrapped human bodies in cloth saturated with natural resins as part of the mummification process. Japanese Samurai warriors used special laminating techniques to forge swords that had desirable physical properties. Around the Mediterranean and in the Far East, artisans used a type of composite technology to mold artwork using layers of paper cut to appropriate shapes. The development of fiberglass started in the 1920s, but fiberglass composite materials were not commercialized until after they were exhibited at the 1939 New York World's

Fair [9, 10]. Grade E and C glass fibers are the most commonly used, but there are other grades available. The field of fiberglass reinforced plastics (FRP) began after World War II, when fiberglass reinforced plastic randomness was first fabricated to house radar sets. The boating industry was the first to widely embrace the use of fiberglass reinforced plastics. The light weight of fiberglass reinforced plastic and the ability to mold it to complex shapes made fiberglass composites ideal materials of construction for boat fabrication. The first fiberglass boats produced suffered serious delamination problems early in their useful life [2, 11].

In 1950 fiberglass piping first became a viable alternative to more expensive coated steel, stainless steels and other exotic metal alloy piping. Centrifugally cast fiberglass pipe was offered that year to the oil industry as a solution to corrosion problems. Perrault Fiber casts Corporation of Oklahoma used a patented process to manufacture the first pipe constructed of fiberglass reinforced polyester resin. The company was sold and later became Fiber cast, Inc. America Bond strand also started manufacturing pipe in the early 1950's in southern California. They produced filament-wound pipe for the chemical, industrial and military pipe markets. Fiber cast and America Bond strand purchased fittings from the Conley Corporation of Tulsa Oklahoma. The Conley Corporation patented the molding process and methodology used in the production of fiberglass fittings in 1954. During the 1980's Reinforced Thermosetting-Resin Pipe (RTRP) became known simply as fiberglass piping. Several names are now in common usage [3, 12]. In the late 1960's and early 1970's, FRP materials were being developed that would bring the market for FRP pipe to new heights. FRP was specified in many applications where only specialty alloys had been used and as the applications expanded, FRP was becoming the complete problem solver for corrosion service. Resin manufacturers were developing new polyesters and vinyl esters that were tougher and more resilient. The manufacturers we're developing fabrication methods that improved quality and reduced costs. In 1974 several business projections indicated that FRP was to be the growth industry of the future, but about this same time some plant owners and engineers began to experience frequent piping failures. Many users were questioning the ability of this material to handle the operating stress of process piping [13, 14].

Fiberglass or Fiber Reinforced Plastic (FRP) tubulars have been in use in the oil and gas industry since the 1980's. A wide range of applications have been identified including, but certainly not limited to: storage tanks, production risers, flowlines and offshore platform support systems

(sewage, water disposal etc.) The main reasons for employing FRP as opposed to conventional materials such as carbon steel are the FRP's strong resistance to corrosion, high strength-density ratio, low installation cost, versatility and damage tolerance [15]. In 2005 the fiberglass are interchangeable, but will be referred to as fiberglass from this point forward and it should not be confused with hybrid applications where carbon steel pipe is often lined with or wrapped in fiberglass in order to retain the steel's temperature resistance and to employ the fiberglass' strong resistance to corrosion [16].

Since 2014 the mechanical engineers has been conducted FRP pipe material consists of resins (typically thermoset vinyl ester) and fiberglass were combined together on a mold surface to form various shapes and components to works primarily in structural design and stress analysis of FRP piping, materials and industrial equipment. The resin brings the chemical resistance to the product and is the binder for the glass fiber in the structural laminate. Based on the process conditions, a resin and glass type is selected and composite pipe systems and equipment are suitable for a wide range of process streams such as hydrochloric acid [17].

## **1.2 Statement of problem**

The raw material of reinforcement glass fiber sheet layers used for only water reserved tank manufacturing in World Fiber Company at Addis Ababa city around Gord Shola town. Fiber Reinforced Plastic composite pipe are not wide performed to manufactured in our countries Ethiopia and there is shortage of imported company for composite pipe materials available. There company not to fabricate also tubular body of pipe form the chopped strand mat and woven roving of glass reinforcement fiber and based on general purpose of resin matrix. The fabricated FRP pipes used for water supply purpose that not used to steel or plastic pipe materials for minimizing the maintenance and other rework case for constructed buildings and industries.

## **1.3 Objectives**

### **1.3.1 General objective**

The general objective is to fabricate and characterize fiber reinforced plastic (FRP) pipes from reinforcement sheets of glass fiber based on unsaturated polyester resin of thermosetting matrix using contrived split mold.

### 1.3.2 Specific objectives

The specific objectives of this thesis work are listed below:

- To fabricate FRP pipe of glass fiber reinforcement of chopped strand mat layers.
- To fabricate FRP pipe of glass fiber reinforcement of plain woven roving layers.
- To evaluate mechanical properties such as hardness, compressive strength and water absorption tests.

### 1.4 Scope of thesis

The fiber reinforced pipe fabricated using contrived split mold techniques produce four type of pipe namely, 5 and 7 round layers of chopped strand mat pipe and also, 5 and 7 round layers woven roving pipe product are produces as shown the table below. The manufactured kinds of FRP pipe verifying the product with experimental sessions involve to measure the mechanical properties of compressive strength, water absorption and hardness test.

Table 1.1 Pallet size of CSM and PWR reinforcement of glass fiber sheets

No designations	Stacking sequence (lay-up)	No of round
<b>5CSM</b>	-CSM/CSM/CSM-	5
<b>7CSM</b>	-CSM/CSM/CSM-	7
<b>5PWR</b>	-PWR/PWR/PWR-	5
<b>7PWR</b>	-PWR/PWR/PWR-	7

Note: *CSM-Chopped Strand Mat, PWR-Plain Woven Roving*

### 1.5 Significance of the thesis

The main significance of this thesis is:

- Better mechanical and thermal properties performance of fiber reinforced plastic pipe than steel and plastic pipelines.
- The reinforcement row material used for only water reserved tank fabrication and sheets while it also used for productions of pipe.
- The material which has minimized its overall cost, light weight and increase lifetime products from composite material are fiber reinforced plastic pipe.

- To reduce the failure of water supply purposes of pipe usage and minimizing the shortage of water distribution area.
- To increasing the fabrication type of fiber reinforced pipe product techniques and reduce the wastage of matrix material.

## **1.6 Limitation of work**

The FRP pipe manufactured in manual system by using contrived mold method has new concept and difficult to find the related documents with similar to it. Their lack of several types of chopped strand mat, woven roving sheet layers of glass reinforcement fiber and general purpose of resin matrix availability. There is not have the proto type manufacturing industries to fabricate the design specification of each components of mold part. The products need much time delay for each curing time 24 hrs.

## **1.8 Arrangement of thesis**

In this section, an overview of the task involved in accomplishing the overall objective of the study and summary of the contents are given. These tasks are described in detail in the subsequent chapter.

**Chapter one** has been included, the introduction of FRP pipe, background, objective, statement of problem, scope of thesis, motivation of study, significance of work and limitation of study.

**Chapter two** has the compressive literature survey of FRP pipe review of some journal articles, conference papers, which were referred during study. Also, in relation and comparison with previous works, what is done in this study has been stated.

**Chapter three** will described the raw materials, method, parameters and composite that is relevant to this research (such as thermosetting matrix composite, glass mat fiber). The whole equipment and accessories of FRP pipe reinforcements in chopped strand mat and plain-woven roving sheet layers preparation techniques.

**Chapter four** will shows the fabrication process of FRP pipe that prepared in a form of chopped strand mat and plain-woven roving glass layers in 5 and 7 rolled layers and specimen preparation of GRP pipes for mechanical tasting in hardness, compression and optical microscope structure.

**Chapter five** has distinguishes the result and discussion of experimental work of GRP pipe made from chopped strand mat (CSM) and plain-woven roving (PWR) sheet layer pipes product from mechanical tested results explained with graph.

**Chapter six** has the last chapter covers conclusion drawn from the results explained in chapter five, recommendations and future works.

## Chapter two

### Literature review

#### 2.1 Introduction

Fiber-reinforced polymer composites are meeting an increasing demand as construction material due to their excellent properties including light weight, high specific strength, corrosion resistance, and low maintenance cost. Long-term durability of glass-epoxy composite pipeline in service is an industrial important issue mainly because the consequences of failure are severe in oil and gas applications [18]. Some of the those problems that occur during the manufacturing and after installation of FRP are such as formation of air bubbles between the polyester resin layer and the surface film or the mold surface, Moisture formed in between the tubing outer and inner layers after installation, heat released in between the layers of E-Glass FRP Pipes due to exothermic reaction which results in the formation of cracks on the surface of the pipe. The operation temperature is another important variable that determines the degradation resistance of the E-Glass composite pipes. The temperature determines various factors such as moisture, air bubbles, heat produced within the pipes [19].

The manufacturer of glass epoxy reinforced pipe by arranging of the fibers and the winding angle was controlled for specific designs by coordinating mandrel rotation and carriage speed in order to obtain the required axial and hoop properties. Careful monitoring had required to ensure that the mandrel was fully covered by the resin wetted fiber bundles and to produce a product with consistent wall thickness. Usually, numbers of fiber tow were used together to produce bigger bandwidth and reduce winding time. A diagram of the filament winding process for producing GRE parts is shown in Figure 2.1. The mandrel is then rotated during the curing processes to maintain uniformity in resin content around the circumference of the pipe [20].

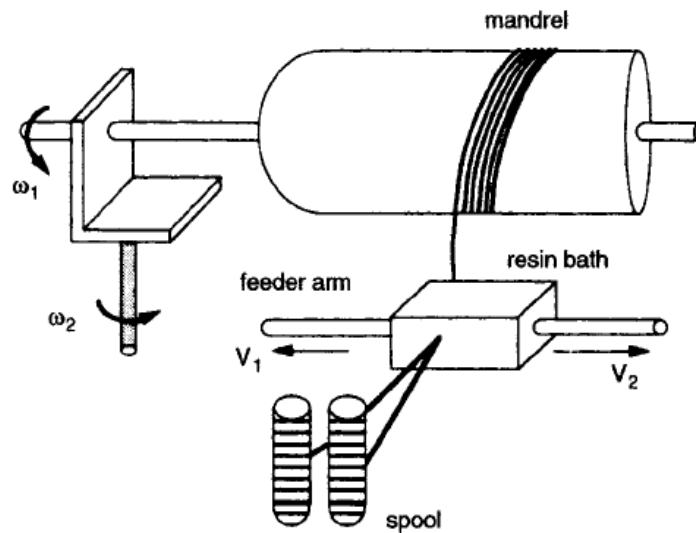


Figure 2.1 Schematic diagrams of filament winding for producing FRP pipes [20]

Filament-wound GRE pipe is essentially a layered of unidirectional plies angled sequentially at  $\pm\theta^\circ$ , to the axial direction. In this investigation, the pipes were produced at the  $\pm 55^\circ$  angle, which is considered to be the optimum angle for GRE pipes when subjected to internal pressure alone. However, this may not result in weep age failure since the cracks are restrained by the neighboring ply at a different orientation, which may still remain intact. This suggests that weep age could have precipitated from combinations of matrix cracks with other forms of damage, for example inter laminar cracks or even delamination between plies. In earlier investigations, many have explained this non-linear response as a consequence of matrix cracking within plies. As the crack density increases with increasing load, the non-linearity becomes more pronounced at higher loads and is found to correspond to degradation in the mechanical properties of the pipe [21].

The manufacturing processes used for FRP are often very different from those used with conventional structural materials, the materials we are considering in this study are the continuous fiber reinforced plastic, based on fine filaments, which are very long with respect to their diameters. There are many aspects of composite manufacture which are common with textile processing. The flexibility of fibers allows them to be woven or wound onto mandrels so that complex forms can be produced which, when impregnated with plastic, and then cured, can lead directly to the final product which requires little or no extra finishing. In this way the total cost of manufacturing a component with a composite material can be reduced, compared with traditional

materials. Alternatively, fibers can be chopped and sprayed together with the resin onto an open mold. This technique is useful for large structures including boat hulls but is also used for other smaller low cost structures. The matrix properties determine the resistance of the FRP to most of the degradative processes, for instance impact damage, delamination, water absorption, chemical attack and high-temperature creep, which cause failure of the structure.

## **2.2 Pipe materials and properties**

The chemical resistance and mechanical properties of glass fiber–reinforced plastic pipes for oil, gas, and power-plant Applications. The results of a studied to evaluate the chemical resistance and mechanical properties of GFRP pipes for application in oil and gas plants are presented in this paper. Pipe specimens were preconditioned by filling them with 7.5% HCl, 8% H<sub>2</sub>SO<sub>4</sub>, and a mixture of 2% NaOH and 2% KMnO<sub>4</sub> solutions maintained at 63°C. The fresh, preconditioned, and exposed pipe specimens were tested to evaluate their axial and hoop tensile strength, water absorption, and loss on ignition. The experimental results did not exhibit major changes in the properties of evaluating pipes owing to exposure to clean and oily water at high temperature and pressure. There was minimal or no loss in the axial and hoop strength of the preconditioned or exposed pipes. The absorption and loss of ignition did not increase significantly both due to pre-conditioning and evaluated exposure conditions. The results indicate that GFRP pipes are suitable for application in the oil and gas industry [22].

The influence of moisture absorption on the creep of GRP composite pipes obtained from standard test methods under ring deflection conditions were used to determine the long-term circumferential modulus. Creep behavior in an aqueous (potable water) environment of preconditioned and unconditioned GRP pipes under lateral deflection. The preconditioning at 25°C and 50°C displayed a strong influence on the initial stiffness and on the viscoelastic behavior. The moisture influence on mechanical behavior of GRP pipes appears to be negligible, at least during the time span analyzed less than 10,000 hours [23].

## **2.3 FRP Pipe fabrication and matrix materials**

FRP Pipes analyzed by a lot of researchers from various aspects in accordance to the growing demand of pipes in industrial applications. From different journal papers, Articles, conference papers which have done on fiber reinforced plastic pipe literature listed below. The failures in the field of manufacturing and installation of E-glass fiber reinforced pipes (GFRP).Some of the

failures which are mainly encountered after the installation of E-Glass fiber reinforced pipes are the formation of air bubbles in between the polyester resin layer and the surface film, dispersion of moisture in between the tubing outer and inner layers after installation, heat released in between the layers of E-glass fiber reinforced pipes due to exothermic reaction which in turn results in the formation of cracks on the surface of the pipe [24].

The effect of stacking sequence on low velocity impact response and damage formation in hybrid composite pipes under internal pressure. They concluded that maximum contact force, maximum displacement, contact duration and absorbed energy value increase with increasing impact energy and maximum contact force values are obtained at CGG specimens for all impact energy levels and terms of rebound energy, the response of the GCG sample is better than that of the other sample. Especially, in GGC specimens, the specimens cannot deform elastically due to the brittle character of carbon fiber layer and lead to damage initiation and stacking sequence of hybrid pipe greatly affects the damage formation. It is concluded that this event results in an increase of damage formation and progression. It is also resulting in increased energy absorption. Depends on the displacement in the radial direction during impact. In this study, the smallest amount of displacement was obtained in the CGG sample while the greatest amount of displacement obtained at the GGC sample [25].

The effect of temperature on mechanical Properties of Glass Reinforced Plastic GRP pipe, work the effect of temperature on the different properties of glass reinforced plastic pipe is studied. Thermal treatment of the GRP pipe at five temperature levels (25, 50, 100, 150 and 200°C) as well as three times of exposure (60, 120 and 180 minutes) is adopted. The mechanical properties such as tensile strength, compressive strength and hardness at different temperatures are studied. The results show that temperature has considerable effect on different properties in it. The results of the investigations show that the tensile strength, compressive strength and hardness for pipe composite decrease proportionally to temperature increase. This reduction may be caused by the effect of temperature on the polyester resin [26].

The impact-induced damage to glass fiber reinforced epoxy pipes. The high mechanical performance of glass-fiber reinforced epoxy pipes and structures may be adversely affected by their low resistance to impact loadings. The low-velocity impact loads are particularly more dangerous as their damage to the structural integrity of the composite pipes often goes undetected.

And a finite element model of pipe is developed and used in conjunction with failure criteria based on three-dimensional state of stress to predict layer damage under low-velocity impact and damage modes occurring in a composite structure subjected to transverse impact loading include: matrix tensile cracking, matrix compressive/shear failure, fiber breakage (tensile or compressive) and ply separation [27]. The fiber tensile and compressive failure modes are governed by the maximum stress criterion where the fiber failure occurs when the maximum stress in the fiber reaches the tensile strength under tension or buckling strength under compression. The estimated load–time traces correlate well with experimental results obtained earlier and published numerical results. Matrix cracking happens early during the loading period, causing a sudden drop in the impact load. The unloading event at 12 J is mainly elastic for higher impact energy, while most of the damage happens at the maximum load it is observed that all three types of failures continue to occur in the matrix, fiber and their interface [28].

## **2.4 Thermosetting Plastic**

A thermosetting plastic, also known as a thermostat, is polymer material that irreversibly cures. It is a pre-polymer in a soft solid or viscous state that changes irreversibly into an invisible, insoluble polymer network by curing. Curing can be induced by the action of heat or suitable radiation, or both. Thermosetting plastics are made up of lines of molecules which are heavily cross-linked. It creates a rigid molecular structure. They may be heated the first time and shaped, but they become permanently stiff and solid. Most thermostats consist of a network of carbon atoms covalently bonded to form a rigid solid. Sometimes nitrogen, oxygen, sulfur or other atoms are also covalently bonded into a thermostat network structure. Thermosets are generally stronger than thermoplastics due to their 3D network of bonds and better suited to high temperature applications [3].

The analytical method for stress analysis of filament wound thick composite pipes subjected to internal pressure. Both hoop and radial stress components have been calculated for symmetric stacking sequence. Five main variables as pipe thickness, inner and outer pipe radius, winding angle, internal pressure and in-plane mechanical properties were assumed as random parameters. Thus, stochastic analysis of hoop stress was conducted using Monte-Carlo method [29]. Probabilistic analysis of the mechanical response revealed that pipe thickness and internal pressure variation significantly influence the stress distribution. It have performed stochastic FE modelling to study the variations of stress components in an industrial GRP pipe with ply configuration of as

a case study. They have shown that the influence of winding angle variations, even for very small values, is much more pronounced than the fluctuation of fiber volume fraction [30].

The moisture effects on the thermal and creep performance of carbon fiber/epoxy composites for structural pipeline repair experiments tested in flexural creep after is exposed to water for over 18 months. Flexural testing was performed in a dynamic mechanical analyzer and time, temperature superposition was used to generate master curves by manual and constant activation energy approaches. In addition to the time–temperature superposition, an analysis of activation energy based on frequency dependent gradient temperature was performed. Time temperature superposition held for temperatures between 30°C and 75°C for material and had been immersed in water for up to 18 months exhibited larger creep at design lifetimes of 50 years when compared to samples that had been stored in ambient conditions. Tensile creep testing results indicate that the composite should be safe from creep rupture at 65% UTS loading for a 50-year lifetime [31].

## **2.5 Natural Fiber vs Synthetic Fiber**

The synthetic fiber-reinforced thermoplastic composites have better mechanical properties than the natural fibers, but they are not environmentally friendly. Some advantages of natural fibers are low abrasion resistance, low density, high toughness, acceptable specific strength properties, good thermal properties, enhanced energy recovery, biodegradability and so on [4]. In this form, both fibers and matrix remind their physical and chemical identities, yet they produce a combination of properties that cannot be achieved with either of the constituents acting alone. Many fiber-reinforced composite materials offer a combination of strength and modulus that are either comparable to or better than many traditional metallic materials. In general, fibers are the principal load-carrying members, while the surrounding matrix keeps them in the desired location and orientation, acts as a load transfer medium between them, and protects them from environmental damages due to elevated temperatures and humidity [32].

Majority of studies in this field have evaluated the influence of winding angles on the failure of filament wound pipes experimentally and/or theoretically. Early studies in this field were concentrating on the pure GFRP and small diameter tubes. They were usually performed just experimentally and limited attempts have been done to correlate the experimental observations with simple theoretical evaluations. Recently, more sophisticated theoretical modelling techniques are conducted to develop predictive tools for predicting failure of GFRP pipes with larger

diameters under various loading conditions. Analyzing GRP mortar pipes have also received more interest among researchers in recent years. The theoretically examined widely accepted angle 55 as the optimum winding angle of filament wound pressure vessels and axially loaded pressure pipes using reliability analysis. They have used CLT for stress analysis and Tsai–Wu failure criterion as the limit state function. They have concluded that the Young's modulus of the matrix and the transverse strength of the ply are the most important parameters resulted in variations of the optimum winding angle [33].

## **2.6 Delamination**

Another commonly observed failure mode for FRP pipes is delamination, which is also referred to as inter laminar cracks between composite layers. This type of failure is dominated by the properties of the matrix, and given that matrix strength and toughness tend to be relatively low, laminated composites are hence prone to the development of delamination. As there is relatively little resistance to crack growth in the fiber direction, the cracks, once initiated, grow rapidly in this direction. However, the cracks are restrained by their respective layers due to plies of different orientation lying above and below, which may differ considerably in stiffness properties. As a result, a multiaxial stress state develops at the crack tips and, once the stress level exceeds the resin failure strength, this may be sufficient to initiate inter-laminar or delamination failure between the two adjacent layers. Delamination increases the possibility of weep age failure by coalescing with transverse cracks, hence creating multiple pathways for fluid to pass through the pipe wall [34].

The fatigue behavior of filament wound GRP pipes with a surface crack under internal pressure. Glass reinforced plastic pipes were made of E-glass/epoxy and tested in an open-ended condition to analyze the fatigue tests of the pipes with a surface crack and standard allows a frequency of 25 cycles per minute and an  $R = 0.05$  stress ratio. Tests have been performed at three different maximum stress levels, which were 50%, 40% and 30% of the ultimate hoop stress. The effect of notch-to-depth ratios and hoop stress level ratios were investigated on the fatigue life. In the fatigue tests, the failure only occurred in the region where the surface crack cuts a glass fiber. This failure did not exceed the crack length,  $2c$  or the boundary of winding angle. At first stage of the delamination propagation, the area rapidly increased and then slowed down. Failure in the second stage, the remaining lamina failed as like smooth pipe, having the same stacking sequence under

the same fatigue conditions. Fatigue of the non-notched lamina under a surface crack behaved identically to the non-notched GRP pipe [35, 36].

Plastic micro buckling is the dominant mechanism of compressive failure in plastic-matrix composites, especially to these FRP possess a compressive strength of less than 60% of their tensile strength. Plastic micro buckling is also an important failure mechanism in natural composite, the woods. The compressive strength is controlled by fiber misalignment together with plastic shear deformation in the matrix, for the woven reinforced plastic matrix composite, the micro-buckles form at many of the cross-over point of neighboring tow. This occurs by the buckling of a surface layer from a subsurface de-bond. It is observed in both ceramic matrix and plastic matrix composites. Post-impact compressive strength is often a concern in the use of composites, as the impact event leads to a large de-bond. Subsequent compressive loading can induce buckle-delamination growth. Buckle delamination is associated with a low matrix toughness and the presence of a large subsurface flaw [37].

## **2.7 Weep age**

Weep age is a common type of leakage failure in filament wound FRP pipes as a result of the progressive damage caused by transverse matrix cracking running parallel to the fiber through-thickness matrix cracks form and propagate due to the integrated effects of transverse tensile and shear stresses. Develop either from the effect of long-term static pressure (static fatigue), repeated pressure (cyclic fatigue) or a combination of both. This damage mode normally occurs at load levels considerably lower than that of structural bursting or collapse failures. The cracks start from the de-bonding process between fibers and the matrix interface. Once de-bonding takes place, there will be less surface area for stress distribution. This will initiate the development of stress concentrations within the composite system which, in turn, causes further de-bonding. Ultimately, de-bonding combined to form a crack parallel to the fibers which then grow in a plane parallel to them. Weep age occurs once the crack concentration increases to a critical level where a fluid path is possible through the pipe wall. Weep age failure is categorized as functional failure due to slow leakage through the pipe wall while it still maintains its structural integrity [38, 39].

## **2.8 Fiber breakage**

Fiber breakage is the final sequence of the damage mode in FRP pipes. When it occurs, the specimen is considered to have lost its structural integrity before progressing quickly to total

failure. The combinations of damage modes spread within laminates until either tensile stress in the fibers exceed the limiting strength of the glass or macro cracks which have nucleated from combinations of inter laminar and intra laminar cracks grow catastrophically. This is often followed by sudden bursting, leaving the fracture area with very little of the structure of the wound pipe. The GRE pipes to failure at various winding angles and no significant fiber rotation prior to weep age failure in axial stress. However, after weep age was observed, the matrix cracks became very extensive and the pipes developed a large axial elongation and obvious circumferential contractions where the fibers rotated towards an optimum angle of  $\pm 55^\circ$ . Pipes then burst abruptly due to successive and continuous fiber breakage. This can normally be seen from massive macro cracks parallel to the fiber orientation in which the minimum necessary amount of energy has been dissipated for the fibers to pull out and fracture [6].

## **2.9 Effect of winding angle on the strength of FRP pipe**

The advances in today's modern computer-controlled filament winding machines have paved the way for the generation of almost any winding angle in FRP pipes. The most common filament wound pipes normally have fibers wound in helices at angles of  $\pm\theta^\circ$  to the pipe's axial direction. To achieve the optimum design criteria, the winding angle of the fibers is orientated in directions that offer the maximum working loads for particular applications. The failure analysis of  $(+55^\circ)^3$  filament wound composite pipes with an inclined surface crack under static internal pressure conducts failure analysis of filament wound glass reinforced plastic (GRP) pipes made of E glass/epoxy with an inclined surface crack under open-ended internal pressure. Test specimens are composed of six anti symmetric layers with  $55^\circ$  winding angles and tests have been performed at seven different crack angles:  $0^\circ$ ,  $15^\circ$ ,  $30^\circ$ ,  $60^\circ$ ,  $45^\circ$ ,  $75^\circ$ , and  $90^\circ$ . As the angle of the crack in GRP pipes increases, the burst pressure increases and the effect of the crack angles decreases. Therefore, the burst strength is highest for  $55^\circ$  GRP pipe surface crack angle. One of the other reasons for the increase of the burst pressure is the decrease of the crack length from  $0^\circ$  to  $90^\circ$ . Examination of the crack zone reveals that the crack growth started with delamination and failure band was formed by an increase in delamination [40].

## **2.10 Effect of environment on the strength of FRP pipe**

One of the major problems in polymer matrix composites concerns durability under natural environmental exposure such as to moisture and temperature. These conditions are generally

recognized to cause degradations in strength and mechanical property by the matrix properties. Reis et al investigated the influence of ageing in the failure pressure of a GFRP pipe used in oil industry. The sample was used per ageing period: 0, 2, 4 and 6 months of degradation performed on pipes submitted to accelerated ageing combining hydraulic pressure and temperature (1 MPa and 80 °C). Pressure can be strongly affected by the ageing period and tensile tests also have been performed, showing a brittle-elastic behavior. For this particular composite, the stiffness of the tensile specimen is not significantly affected by the ageing time, but the ultimate tensile stress is affected by the ageing time [41].

The influence of hydrothermal ageing on the compressive behavior of glass fiber/epoxy composite pipes. The pipes were then hydrothermally aged in tap water at a constant temperature of 80 °C for periods of 500, 1000, and 1500 h. The tests were also performed at temperatures ranging from room temperature at 25 °C to 45 °C and 65 °C to study the response of the pipes at elevated temperatures. The results indicate that the strength of the GFRP pipes significantly decreases with an increase in the temperature and ageing period. On the contrary, the strength increases as the winding angles decrease. As the winding angle increases, the magnitude of the fiber orientation angle increases away from the direction of the loading and becomes more perpendicular to the loading, which causes the cracks to propagate quickly through the material. The pipes exhibited a higher failure strain when the resin matrix softened due to elevated temperatures, and thus the specimens deformed at a lower compressive stresses and Ageing caused the fiber-matrix bonding to degrade because of moisture absorption, which consequently reduced the strength of the GFRP pipes. During the compression process, the strength of the GFRP pipes significantly decreased as the temperature is increased [42]. The Subsea flowline buckle capacity considering uncertainty in pipe–soil interaction. The investigations include the random nature of flowline embedment and out-of-straightness, both of which influence the flowline buckle capacity. Improved estimates of the range of flowline buckle capacities are likely achieved, leading to increased confidence in their design. The flowline embodiment is influenced by the installation method and events occurring during its installation, such as sea state-induced pipe motions at the seafloor touchdown location. The designer is free to select the appropriate descriptive random variable statistics for such events and important feature of the Monte Carlo simulations undertaken here is the use of response surfaces to describe the buckle capacity of the flowline as a result of different combinations of lateral soil breakout resistance and pipe geometric imperfections [43].

The influence of moisture on mechanical properties and damage kinetics of filament wound GRE pipes with diameter of 60 mm, winding pattern of  $[\pm 553]$  and thickness of 2.5 mm. Different tensile tests and viscoelastic analysis have been carried out on neat resin to characterize the mechanism of degradation in composites. The influence of aging on composites have been studied using tensile fatigue tests and repeated progressive loading tests under internal pressure and fixed ends. It was observed that the water absorption rate and damage level are coupled together. Thus, a coupling method was proposed to take into account aforementioned interrelation for one cycle of absorption/desorption [44].

The experimentally assessed the influence of water absorption on durability of GRP pipes. Three different pipes with diameter of 500 mm have been studied: centrifugally casted GRV mortar pipe and filament wound GRE and GRP mortar pipes with winding angle of  $\pm 73$  and hoop winding, respectively. The influence of moisture on mechanical performance (inter-laminar shear strength, flexural modulus and strength) and glass transition temperature have been investigated using three-point bending, inter-laminar shear tests and dynamic mechanical analyzer. Water absorption was also theoretically predicted and good agreement has been reported between theoretical prediction and experimental data just for GRV mortar pipe [45, 46].

The influence of humidity and temperature on the properties of filament wound GRV pipes have been experimentally and numerically studied by exposed to both water and sea water environments. It was reported that moisture absorption percentage increases when the immersion temperature rises. On the other hand, required time for experiencing saturation was reduced at higher temperatures. Mechanical degradation of pipe samples subjected to humid conditions have been examined using buckling experiments and a decrease in the failure force has been seen especially at higher elevated temperatures. Moreover, Scanning Electron Microscopy (SEM) images displayed that the strength of fiber–matrix interface was weakened at higher temperatures. Predicting saturation time of the aged specimens, experimental data and simulations results of the moisture diffusion were in a very good agreement [47].

Experimentally monitored the degradation process of GRV pipes produced by continuous filament winding technology exposed to solar radiation. Small ring sections with 12-mm width have been taken from GRV pipes with diameter of 150 mm and exposed to outdoor environmental conditions up to 60 months. Glass transition temperature and the degree of crosslinking have been examined

using differential scanning calorimetry (DSC) with respect to the time. It was evident that all glass transition temperature, degree of crosslinking and also weight of GRV samples have been affected by outdoor environment influencing tensile strength of investigated GRV pipes. An increase has been initially observed in the tensile strength and then a decreasing trend was seen. The former is attributed to the increase in crosslinking while the later is associated with the weight loss of resin [48].

## **2.12 Effect of filament winding parameters on the strength of FRP pipe**

Other factors that could affect the strength and long-term performance of FRP pipes are the winding parameters during the manufacture of FRP pipes, such as winding tension, winding time and volume fraction. The impact-induced damage to glass fiber reinforced epoxy pipes for high mechanical performance and structures may be adversely affected by their low resistance to impact loadings. To developed and analyzes the composite's structural behavior under low velocity impact. The load and damage histories were obtained for different impact energies (12 J, 35 J, 80 J and 110 J) and for two pipe wall thicknesses (4.5 and 6 mm). Three types of layer failures are found to occur during the low velocity impact event. Matrix cracking happens early during the loading period, causing a sudden drop in the impact load and denomination followed by fiber breakage. For higher impact energy, while most of the damage happens at the maximum load it is observed that all three types of failures continue to occur in the matrix. This is translated by a number of sharp load drops occurring shortly after the maximum load and by higher absorbed energy resulting in permanent deflection of the pipe wall [49].

The repairing impact damaged fiber reinforced composite pipes by external wrapping with composite patches layers on the burst pressure of low velocity impact damaged tubes that have been repaired with composite patches were investigated. The pre-stressed glass fiber reinforced plastic tubes were damaged by applying low velocity impacts at different energy levels (5, 10 and 15 J). The damaged areas of the affected tubes were repaired with 2, 4 and 6 layers of glass/epoxy fabrics. As the number of patch layers on patch repaired GFRP composite tubes increases, the burst pressure of those specimens tends to improve as compared with unprepared ones. However; four specimens affected with 10 J of impact energy, only the specimens with four- and six-layered patches exhibited the explosion as their sign of ultimate failure having two layered patches gushing oil jets as their sign of ultimate failure. In case of specimens with 15 J of impact energy. The results

show that repairing by external wrapping with a composite patch supplied sufficient retrofitting of impact damaged composite tubes [50].

Stress modeling of pipelines strengthened with advanced composite materials. To provide stress expressions on the interaction between the different stresses exerted on pipe walls and the effects of composite sheets on the circumferential stresses of damaged pipe walls. The effects of three different sheets: Glass FRP, Aramid FRP, and Carbon FRP on the performance of pipe walls will be compared analytically. There experimented of carbon fiber composites perform better than glass or aramid in improving the ultimate internal pressure capacity of the pipes, and therefore, significantly enhance the strength, durability, and corrosive properties [37]. Various GRE pipes underwent hydrostatic and biaxial load conditions up to temperatures of 95 °C. This test has provided an alternative to the 1000-hour test procedure for the reconfirmation of the design basis of pipes. This research found that different stress ratios have different and distinct failure modes. They also showed that the UEWS-based failure envelope degraded at elevated temperatures except for 2:1 loading. Krishnan et al. extended the investigation and research extensively on the effects of the winding angle on the behavior of glass/epoxy pipes under multiaxial cyclic loading on different winding angle;  $\pm 45^\circ$ ,  $\pm 55^\circ$ , and  $\pm 63^\circ$  [51].

### **2.13 Centrifugal casting**

Centrifugal casting is an industrial process for the production of pipes, masts (e.g. flagpoles), rollers and containers. The casting equipment consists of a cylinder (often made of steel), which lays on a series of bearings and can rotate with adjustable speed. The drive is via either V-belts or rollers, upon which the cylinder rests. Very often, a mixture of glass fibers and resin is dosed simultaneously to the rotating cylinder. As a result of the centrifugal forces, the glass fibers are impregnated and optimally de-aerated. A tube with a good surface quality is the result. The mechanical properties of the tubes are determined by the amount of reinforcing fibers as well as by the turning speed of the cylinder [52].

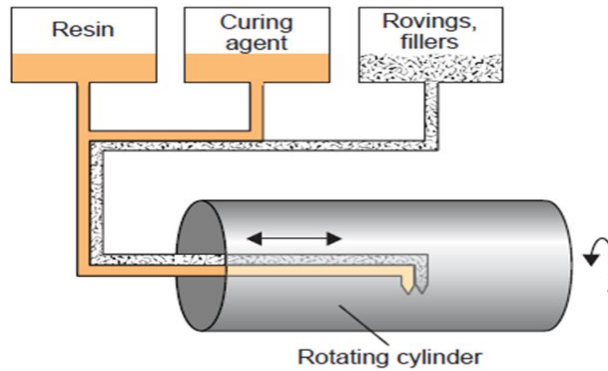


Figure 2.2 Centrifugal casting [52].

### 2.15 Pultrusion

Pultrusion is a technique to produce glass fiber-reinforced profiles. Dry glass fiber rovings are pulled through a resin bath in which they are impregnated with UP resin. After impregnation, the fibers are pulled through a heated die in which the resin cures at temperatures of 110 to 160°C. The die has the shape of the end product. After curing in the die, the profiles are cooled down and cut to the desired length. With the Pultrusion process, virtually every desired profile can be manufactured. A wide range of standard industrial profiles is available in the usual U-, I- and O-shapes, but with Pultrusion, very complicated profiles can also be made. These profiles find their use in a wide variety of end markets. Pressing processes are used for the production of complicated shapes with a high reproducibility. These processes are typically suited for large-series production. There are two distinctly different pressing processes, i.e. wet pressing and hot press molding using a semi-finished intermediate such as SMC (sheet molding compound) or BMC (bulk molding compound) [11].

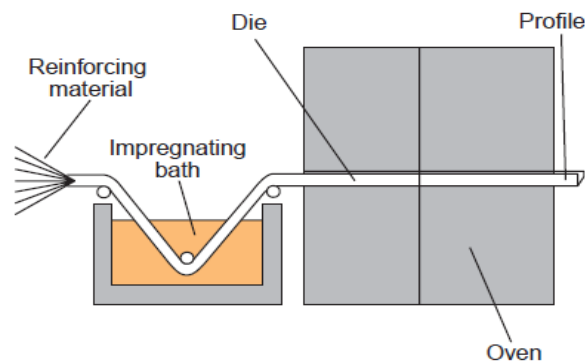


Figure 2.3 Pultrusion process [11]

## **2.16 Conclusion of literature reviews**

The fiber reinforced plastic pipes were usually fabricated in filament winding methods with continuous reinforcement fiber type in filament winding machine. This type of manufacturing method needed high investment cost and high wastage of thermosetting matrix resin. For light duty of FRP pipe purpose to produce products in manual fabrication of pipe from cloth like sheet reinforcement fiber material for water tank manufacturing equipment's. Here to fabricate the reinforcement of fiber in form of sheet like chopped strand mat and woven roving of glass fiber manually rolls in mandrel shaft on table and after purring resin matrix rotate in on lathe machine to impregnation uniformly the reinforcement and resin matrix of pipe thickness.

## **2.17 Gap analysis**

As reviewed in the previous section, numerous investigations have been conducted to fabricate and characterize mechanical performance of FRP pipes from various viewpoints. There are still some important and challenging aspects which are still in need of deeper understanding and discussion. The most important issues which have not been addressed can be itemized as below.

- Fabrications of FRP pipe from glass fiber reinforcement (chopped strand mat & plain woven roving) sheets based on thermoset resin matrix by using contrived split mold method.
- Reduce wastage of resin matrix material and the overall manufacturing cost.
- Upgrade production of FRP pipe with new concepts using lathe machine that similar to centrifugal casting techniques.
- The glass fiber with a form of chopped strand mat and woven roving layers roll to made FRP pipe with UP resin using lath machine speed for uniform embodiment of composite material production.

# Chapter three

## Material and methodology

### 3.1 Materials

The material required to preformed FRP pipe from glass reinforcement fiber layers in a form of chopped strand mat, woven roving sheet layers and unsaturated polyester resin matrix are seals from World Fiber glass and water proofing Engineering importers Company in Addis Ababa, Ethiopian.

#### 3.1.1 Reinforcement Material

The type of strand mat material can be used in the present fabricates from several kind of glass fibers used in my thesis become E-glass types. The E- glass fibers are the most common of all reinforcing fibers for polymer matrix composites, which is composed primarily of silica ( $\text{SiO}_2$ ) backbone in the form of  $(-\text{SiO}_4-)_n$  tetrahedral. The principal advantages of glass fibers are their low cost and high strength. The disadvantages are low modulus and poor abrasion resistance, which decreases its potential strength, and poor adhesion to polymer matrix resins, particularly in the presence of moisture and poor adhesion requires the use of chemical coupling agents on the surface of the fibers [11].

Table 3.1 Properties of E-glass fibers and polyester resin

<b>Fiber</b>	<b>Density (g/cm<sup>3</sup>)</b>	<b>Elongation (%)</b>	<b>Tensile strength (MPa)</b>	<b>Tensile modulus (GPa)</b>
<b>E-glass</b>	2.60	4.8	2445	73.1
<b>polyester resin</b>	1.10-1.15	1-5	34.5-103.5	2.1-3.45

##### 3.1.1.1 Chopped Strand Mat

The chopped strand mat for hand lay-up is a medium fiber, multi-chop length chopped strand mat bonded together using an emulsion binder. It consists of glass fibers laid randomly across each other and held together by a binder. Chopped Strand Mat is produced by random distribution of chopped strands (usually 50 millimeters in length) into a uniform bonded mat and no unidirectional physical properties. It is most widely used for products, including such as articles as boats, bath tubs, tanks and pipes make by hand lay-up method. It has excellent wetting and durability, high tensile strength, and allows easy removal of trapped air-bubbles. They have been specially developed for use in wet-formed mats and veils, which are processed in either acidic or neutral white-water systems. The woven roving as a general rule estimate the resin/reinforcement ratio of

1:2 to 2.5 by weight and available in a variety of weaves, weights, widths and finishes suit a wide range of applications [53].



Figure 3.1 Chopped strand mat layers.

Table 3.2 Standard roll weight and length of chopped strand mat

Product Designation	standard roll weight and length			
	width 104cm		width 186 cm	
	Weight kg	Length m	Weight kg	Length m
MC 300A	30	96	53	96
MC 3800A	30	76	53	76
MC 450A	30	64	53	64
MC600A	30	48	53	48

### 3.1.1.2 Plain woven roving

Woven Roving is made from continuous glass fiber roving which are interlaced into the heavy weight fabric and compatible with most resin systems. Used in most cases to increase the flexural and impact strength of laminates. The ideal for multi-layer hand lay-up applications where greater material strength is required and good drape ability, wet out and cost effective. The woven roving as a general rule estimate the resin/reinforcement ratio of 1:1 to 1.5 by weight and available in a variety of weaves, weights, widths and finishes suit a wide range of applications. Woven Roving is very thick and used for large, high-strength moldings, such as yachts, fishing boats, tanks and architectural structures [53].



Figure 3.2 plain woven roving

Table 3.3 Standard roll weight and length of plain-woven roving

<b>Product designation</b>	<b>Thickness mm</b>	<b>Width cm</b>	<b>Roll length m</b>
<b>WR 570C 100</b>	0.7	100	50
<b>WR 800C 100</b>	1.6	100	50

### 3.1.2 Matrix material

The thermoset resin that has better mechanical, thermal and chemical properties have been selected due to high durability, performance and optimistic resistance of alternative environment condition. The composite resins are produced to demanding standards and have earned a worldwide reputation for quality and reliability and resin and catalyst are mixed and then undergo a non-reversible chemical reaction to form a hard, infusible product. Some thermoset resin such as polyester and epoxy cure by mechanisms that do not produce any volatile by product and thus are much easier to process of addition reactions [50]. From the table below polyester resin matrix selected for making the glass reinforced polyester pipe for the desire products. Due to the availability and material cost of productions and it is compatible with unsaturated polyester resins and is well suited for hand lay-up applications such as auto parts, boats, chemical tanks and pools.

Table 3.4 Usage of FRP based on resin

<b>Properties</b>	<b>FRP polyester piping</b>	<b>FRP epoxy piping</b>
<b>Resin</b>	Polyester/vinyl ester	Epoxy
<b>Temperature</b>	Up to 65°C/ 90°C	Up to 150 °C
<b>Pressure</b>	Gravity to 40 bar G/ full vacuum	Gravity to 200 bar G/ full vacuum
<b>Can handle</b>	All moderate corrosive fluids	All high corrosive fluids

### 3.1.2.1 Unsaturated polyester resin

The matrix resin purchased from Addis Ababa world fiber glass organization of Orgi-Chemie general purpose resins of unsaturated polyester range. The starting material for a thermoset polyester matrix is an unsaturated polyester resin that contains a number of C=C double bonds. It is prepared by the reaction of maleic anhydride and ethylene glycol or propylene glycol. The resulting polymeric liquid is dissolved in a reactive (polymerizable) diluent, such as styrene, which reduces its viscosity and makes it easier to handle. The diluent also contains C=C double bonds and acts as a cross-linking agent by bridging the adjacent polyester molecules at their unsaturation points. Trace amounts of an inhibitor, such as hydroquinone or benzoquinone, are added to the liquid mix to prevent premature polymerization during storage [11].

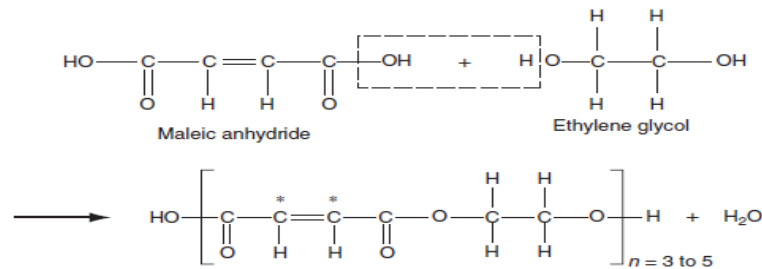


Figure 3.3 Unsaturated polyester resin [11]

The matrix materials used for made the FRP products purchased from Addis Ababa, world fiber and water proofing company that illustrated below. Unsaturated polyester resin has been selected due to higher mechanical, chemical and thermal properties, material cost and availability of resin for GRP pipe fabrications. The laminates made with have good mechanical strength, high rigidity and impact resistance, and excellent dimensional stability. Its curing properties make it especially suitable for fast production processes when used with the recommended curing system [11].



Figure 3.4 Unsaturated polyester resin

### 3.1.3 Hardener

The curing and drying of resin pipe formed by hardener that mixed epoxy resin matrix material with addition of curing agent methyl ethyl ketone peroxide and control the flow of fluid and rise production rate of pipe. The advantages of MEKP catalyst systems are: Optimization of gel time and gel to cure times mean more efficient production and better cure development means a higher quality part, ability to control peak exothermic more precisely in the process and compatible with the resin matrix system. Hardeners are nearly essential to continuously create matrix valuable for its planning reason. Without hardener, polyester don't accomplish anyplace close the noteworthy mechanical and chemical properties that they would with the hardener [11].



Figure 3.5 Hardener (methyl ethyl ketone peroxides)

It is used as a strengthener and a moisture absorber in the composite by mixed with a ratio of unsaturated polyester resin.

Table 3.5 UP resin and MEKP properties

Material	UP resin	MEKP	Combined
Viscosity (mPa.s.)	330	9-23	330
Density (g/cm <sup>3</sup> )	1.10 - 1.15	1.00 - 1.16	1.10- 1.15
Min - max casting thickness	-	-	2 – 75

Methyl Ethyl Ketone Peroxide (MEKP) is used as a catalyst for curing unsaturated polyester resin, in the manufacture of FRP articles, pipes, electric choke, polyester buttons, boats, helmets, motor car bodies, bath tubs, and synthetic marble. The usage of MEKP should be used about 0.5% to 2% by weight of resin, depending upon the ambient temperature and setting time required [39].

Table 3.6 Content of liquid MEKP hardener with UP resin.

UP resin	Liquid catalyst – MEKP (ml)
542.1 gram	10.82 ml of 2%
418.55 gram	8.37 ml of 2%
387.5	7.75 ml of 2%
299	5.98 ml of 2%

The add 2 ml of catalyst per 100 g of resin and stir thoroughly. The minimum ratio of catalyst is 1% and maximum of 3% per weight of the product. The synthetics fiber used for this thesis to fabricate the glass reinforced fiber pipe by using types of glass fiber formed sheet.

### 3.2 Methodology

This section presents the procedures that were taken on the topic to fabricate the FRP pipe by using a contrived split method of the fabricated outer mold and mandrel shaft assembly in proper rolls the chopped and woven strand mat of glass fiber layers to perform that are identified in the objective session. The following procedures in bringing a successful result in this thesis. In general the pipes are manufactured in five distinct stages.

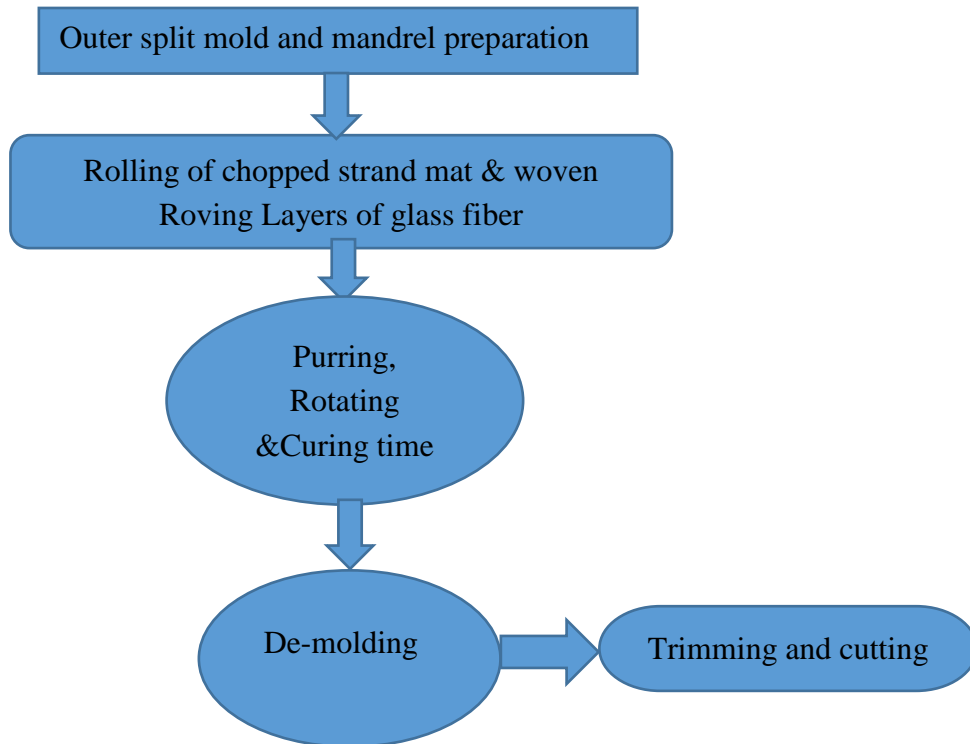


Figure 3.6 Fabrication flow chart of FRP pipe

### 3.2.1 Reinforcement

#### 3.2.1.1 Chopped strand mat

The chopped strand mat with rolls pallet size dimension are 912 X 600m that makes 7 rolling layers on mandrel shaft. The size of chopped strand mat cuts using scissor from rolled strand mat by measuring instrument of meter. The sheet like materials of E- glass fiber in a form of chopped strand mat layers seat on a working table to rolls the size of sheet on mandrel shaft by rotating clock wise direction until the end of each specified sheets that calculated as number of layers restricted in above table.

The starting edge of sheet must be straight line when rolls the mandrel with uniform forces applied till the ending of sheet length and the final edge of sheet seat in half of outer mold to resist the tension that starts to back of rerolling the winding layers. The finally, the rotation of convectional lath machine as the same direction of rolled of mandrel shaft CW direction for prevent the rewinding of the sheets or vice-verse direction with respect to rolling perspectives. The mandrel seat at the edge of working table with respect to strand sheet of chopped mat as we see below figure with pallet size of 7 layers rectangular areal size of sheet that computed with in its no of rolling laminates that leads to make thickness and alter the properties of desire product.

Operation to be made from measuring sheet and cutting up to rolling it as specific pallet size would properly on mandrel will be shown in figure step by steps how the operation implemented for fabrication. As we seen the figure below the mandrel rolls in the direction of chopped sheet to wind and finally twist and inserted in mold before puring matrix.



Figure 3.7 Mandrel seat over chopped strand mat

At some rolling layers of chopped strand sheet looks like on the figure shown below that perform 7 layers of mats accurately lined up with the guidance of rectangular bars as we seen in front of the rollers used to fix the sheet as its place and resist the applied force pulling in to process on

rolling have excess layer appear lead to weak winging operation. When the tension that performs in the operation of rolling sheet like layers have a great roll for made a proper product of material and the matrix embodiment through the whole surface symmetrical impregnations when rotates on lath machines.



Figure 3.8 Rolling method of chopped strand mat

After finished the rolling of sheet it insert into the split pipe and clamped by using bolt and nut for purring the matrix of UP resin mixed with MEKP hardener on the inlet port that appears on the top side of outer split mold. The three kinds of experiment has been implemented within the specified amount of matrix required in the fixed space that available between the mandrel up to internal diameter of split mold.

### 3.2.1.2 Plain woven roving layers

Similar to chopped strand glass fiber in a form of rectangular pallet size with respect to number of layers required for making the product 912×600mm size are rolling in manually with hands till the pallet ends on the mandrel .The woven layers rolled on a working table until the pallet size cut ends as 7 layer performed on mandrel shaft.



Figure 3.9 Rolling of woven roving

### 3.2.2 Matrix material

The thermoset resin used for this thesis as a matrix form which have general purpose unsaturated polyester resin to make the pipe mixed with hardener of methyl ethyl ketone per oxide in 2% of UP resin amount compositions. When the rolling of strand mat ends start to mixes the content needed as fiber amount and then the MEKP hardener as 2% pure it on mold. The material depends on the kind of property when the chopped strand mat layer differ from woven roving it required much amount of resin and purring ports because its thin fiber as whisks form easy interrupted and closed the flows of resin and curing it as some point depressed the it not impregnated the while surface some rolled mate are not uniform and filled part available.



Figure 3.10 Matrix materials of FRP pipe

### 3.2.3 Contrived split mold of FRP pipe

Like a concepts of centrifugal casting is a process used to manufacture hollow pipes with 600mm long goods by applying the compositions of unsaturated polyester resin and glass fiber reinforcement of each plain woven roving and chopped strand mat separately by changes the rolling layers to the inside of a mold that is rotated with 340 RPM and 625 RPM of conventional lath machine, and it subsequently polymerizing (curing) and uniformly distributed the resin system through the hole part of interacted mold cavity. The outer diameter of the finished pipe is determined by the internal diameter of the mold of spilt tubes. The internal diameter (ID) of the finished pipe is variable and is determined by the amount of material introduced into the mold. Other materials, such as sand or fillers, are not used in the process during manufacture of the pipe.

Woven and chopped glass fiber on the mandrel is saturated with resin while the outer molds of spilt pipe that fixed with mandrel shaft between head and tail stock rotates at high speed centrifugal force displaces air from the resin and glass, producing a dense, void-free laminate. Fiber

reinforcement in both the hoop and axial directions affords excellent thermal expansion and beam-bending properties. After a rolling of strand roving mat of glass fibers, UP resin is dosed separately in mold and then fix it to lathe for rotating contrived mold with time interval and rotations. As a result of the centrifugal forces, the glass fibers are impregnated and optimally de-aerated. A pipe with a good surface quality is the result and mechanical properties of the GRP pipe are determined by the amount of reinforcing fibers as well as by the turning speed of the manufactured mold cavity.

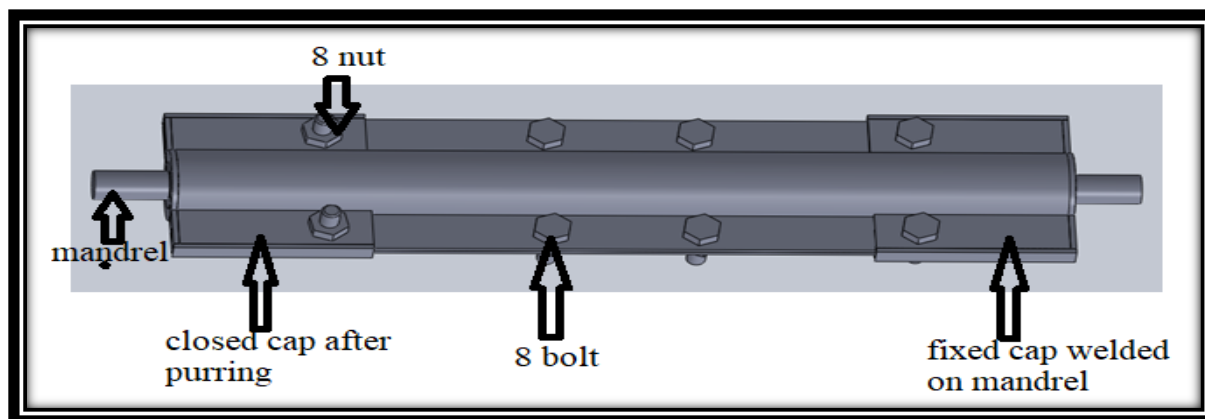


Figure 3.11 Assembly of contrived mold

### 3.2.4 Fabrication steps of FRP pipe

After manufacturing of each component of contrived mold needed parts, the working flow process become the following step consider to assembly each kind of component parts.

- I. With the pallet size lay on working table to rolls the layer by using the mandrel shaft and after rolled clamp both end by plaster.
- II. Insert the rolled mandrel in to outer split pipe on end of shaft having the fixed cap and the split have four holes and its one side of spilt pipe and end cap clamped using bolt and nut fasteners.
- III. Other side of split pipe open and last end of hole not clamped internal have rolled reinforced layers and the purring the mixed resin proportion required to internal part of mold with stand of it.
- IV. After purring closed the inlet port with the closed cap with holes and spilt pipe by bolt and nut

- V. Then the contrived mold uniformly impregnated the reinforcement and resin on lathe machine rotational speed for 5 layers has 340RPM and 7 layers has 625 RPM by fixing between the head and tail stock with 20-minute time duration.
- VI. After that the mold set 24 hours to cure and then demolding the component to removing each part and clean the component for next production implemented.

### **3.2.5 Gelation, Curing and post curing**

Unsaturated polyester resin mixed with organic peroxide hardener (methyl ethyl ketone peroxide) composite this mixture brought to a contrived outer split mold filled with reinforcement of glass fiber which have chopped strand mat or plain-woven roving rolled layers. Meanwhile after purred the UP-resin start having and solid composite is formed this process is called curing. The curing process has works unsaturated polyester resin consist long polyester chain which dissolved in solvent such as styrene moved free and slide passed each other. The curing process starts is the addition of particular substances, organic peroxides, named MEKP hardener when heated or coming in to contact with acceleletor, the MEKP breaks in to two called radicals. And this radical open the double bond on styrene molecule and form new radical this form another styrene molecule and process continuous until it counter unsaturated polyester chain and the molecule connect again anew radical is formed which can open another styrene or polyester chain this process continuous until radical met another radical and combined and basically the curing process consist building small styrene bridge b/n unsaturated polyester molecule and this takes place through up the whole metrics directions.

Generally, the styrene has been built the resin start to gel and heats generated and the heat accelerate the reaction as a result curing process goes faster and faster until the majority the styrene molecules have reacted. At this point the maximum temperature is reached and a strong 3D network formed the temperature starts to drop and the remaining styrene is built in to the network now the final product is finished and ready to use. This is how we make to help the strong and reliable FRP pipes from chopped strand mat and plain-woven roving sheets glass layers. The general-purpose polyester resins perform best if the laminate is completely post cured. It is recommended to mature the products for 24 hours and post curing should be done for minimum of three hours at 800C, or 2-3 weeks at room temperature.

Working life of UP resin is determined after running cure tests on the system to determine what the exact point is when the system gels and how fast the viscosity increases to this gel state in the final stage of curing. The gel time of 20 minutes, but the viscosity increases rapidly between 15 and 20 minutes, the working life may be set at 10 minutes. The gel time is the time when the polymer formation is in its early stages of cross-linking to the point that if the polymer gel state is disturbed then the final polymer will have properties that are not well established. From this experiment we can conclude that the ratio between the polyester resin and methyl ethyl ketone peroxide (hardener) is affecting this composite's gelling time. The higher percentage of the hardener the faster gelling time will be provided.

### 3.3 Samples and sampling

The fabrication of FRP pipes with some different parameters are, types of glass fiber strand mat, number of layers, amount of matrix, time of rotation in lathe machine. The products to overcome the optimized result by changing parameter to be fabricate pipes. The chopped and woven reinforcement in 7 layers rolled in mandrel rotates using lath machine after endorsed the resin with 20 min time duration until curing time that the matrix become dry.

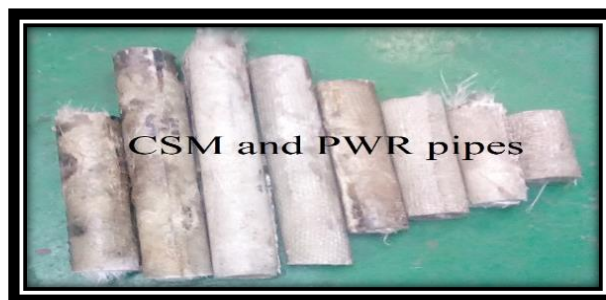


Figure 3.12 Products of CSM and PWR pipes



Figure 3.13 demolding the product by removing half split mold.

The manufactured product when lathe machine operation performed seat the time duration for demolding of the FRP pipe by removing two half split molds of unlocking the clamped and using

hammers. Then after the shaft can be easily removed by cutting both side of product edges and when end mandrel punch it exit from it due to internal releasing agent of oils with plastic sheets.



Figure 3.14 Assembly of mold manufacturing

Defects that face during the first production of pipe was not easily released from the mandrel and starting and ending of rolled layer are not uniformly stacking in its internal rolling mats. The fiber delamination occurs at the starting and ending of fiber. UP resin was not uniformly stacking due to reinforcement shifts its rolled position. And the final product of woven roving pipes tested figure as shown below.



Figure 3.15 First product of GRP pipe

The woven roving has used for high mechanical properties needed for better life span compared to chopped strand layers applying forced used for rolling method of winding it overlaps on mandrel and resins not much required to feed in the whole surface of roving layers. The fabrication of chopped and woven pipe in 5 and 7 layers are performed using the above mold and conventional lath with time duration of 20 min at 340 and 625 rpm. The pipe materials that produce with specified compositions as sown in the figure below.

### 3.3.1 Sample of CSM pipes

The products of CSM reinforcement pipe needs high amount of matrix due to more impregnation process of viscosity flow through fiber of easily pass layer to layer feeding system. The pipes have 5 and 7 layers rolled on mandrel that made varieties reinforcement thickness could be performed

from fixed hollow internal diameter leads to change properties of material. The product opened after 24 hours spent formed as solid casting demolding by necessary accessories that needed to loading and unloading equipment's where been used as the figure illustrated below in half mold has been take off from fabricated product.



Figure 3.16 samples of CSM pipes

### 3.3.2 Samples of PWR pipes

The woven reinforcement would layers overlaps by manually using rolling on 40mm dia. mandrel of 5 and 7 layers with sheet size 644 X 600 and 912 X 600 mm respectively, and purring mixed unsaturated polyester resin with MEKP hardener after clamped the mold parts inlet with a ports on the clamped upper and lower split mold, then immediately fix it on the lathe machine b/n head and tail stock and rotates it with 20 min and rotational speed of 340 and 625 rpm and after 24hr for curing the product, removed from the product from mold. The final product looks like the figure below.



Figure 3.17 Products of PWR pipe

### 3.3.3 Sampling preparation

The products of each four types of FRP pipe are made the required sample specimen for with ASTM standards pipe preparations to each 5CSM, 7CSM, 5PWR and 7PWR pipe products. The specimen that used for mechanical test (hardness & compression), water absorption and optical

microscope. The specimens were cut-out from FRP pipes made by split mold method. The pipes and the machined samples are depicted in Figure below of PWR and CSM pipe.

### 3.3.3.1 Compression test sampling

The compression test involves of deforming a cylindrical hollow specimen of FRP pipe products. Compression test of these samples were operated according to the ASTM D2412 using Universal Testing Machine. The compression test is a suitable method for defining stress strain reaction. The compression test results for the whole sample shows in three major characterized which is compressive strength, compressive strain, and modulus of elasticity due to the compression properties. Each compression properties show the performance of the sample. Universal compressive testing machines (UTM), Venire calipers, stop watch, dial gauge are used the Structure components such as columns and struts subjected to compressive load in applications. The standard length of specimen of longitudinal compression test have 150 mm length of chopped and woven layers of FRP pipe products as shown below.



Figure 3.18 Compression test sample

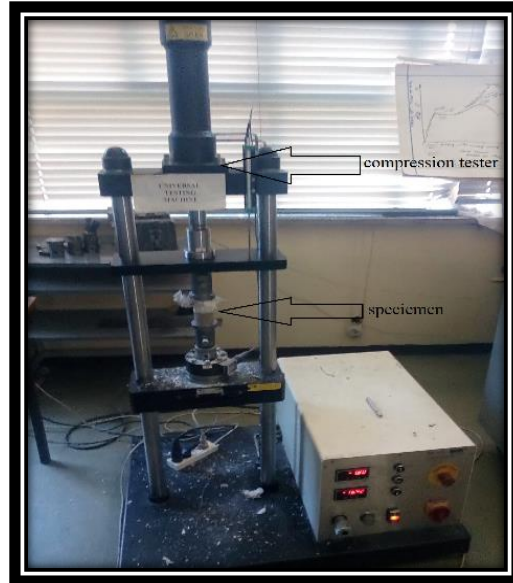


Figure 3.19 Compression testing machine

### 3.3.3.2 Hardness test sampling

The specimen has been prepared from the product of CSM and PWR pipe with 30 X 30 mm plate size shape and other process are carried out in laboratory shop as required sample sizes to be made.



Figure 3.20 Hardness sample of A) PWR pipe & B) CSM pipe

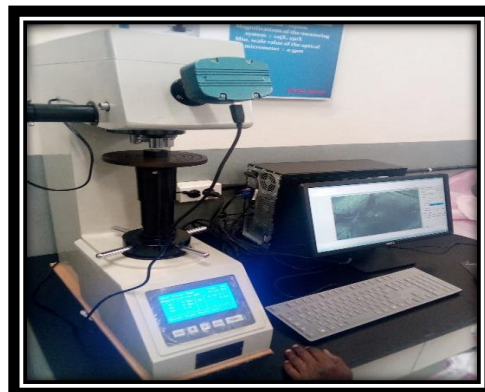


Figure 3.21 Vickers hardness machine

In micro hardness testing, a space is made on the tested by a square-based pyramid diamond indenter through the application. The measure  $d$  of the resultant space is measured with the assistance of a calibrated optical magnifying instrument, and the hardness is assessed as the cruel stretch connected under the indenter for measure used Vickers hardness test. Minimum scale value the optical micro meter is  $0.5\mu\text{m}$ .

$HV = \text{constant} \times \text{test force} / \text{surface area of indenter}$

$$HV = 0.102 \times 2P \left( \sin \frac{136^\circ}{2} \right) / d^2 \quad (8)$$

### 3.3.3.3 Water absorption test sampling

In arrange to test the water absorption properties of the composites, rectangular examples were arranged agreeing to the desired measurement following the ASTM-D570 water absorption specimen dimension standard; having measurements of  $20\text{mm} \times 20\text{mm} \times 5\text{mm}$ . The specimens were dried in room temperature and measured the weight and thickness before immersed in water tank. The water absorption test sample specimen has been weighted before and after immersed in water after 24hrs up to 168hrs by using gram scale measurement.

The formula used for water absorption test analysis can be given as,

$$\text{Water absorption (\%)} = \frac{\text{Final weight} - \text{Original weight}}{\text{Original weight}} \times 100 \quad (9)$$



Figure 3.22 Water absorption sample

## 3.4 Equipment

The equipment tools to run the process of fabrication of FRP pipe from preparation of the mandrel shaft on conventional lath machine cutting tools and load and unload keys, manufacturing of split outer mold pipe preparation required tools and making holes for bolt and nut clamped purpose. After material preparation the flow of production process required equipment, tools is scissor, and

optical microscope. The production of FRP pipe performed by using tools for cutting the sheet to roving it on mandrel.

The strand mat material of chopped and plain-woven glass fiber to form round on the mandrel with specific size and shape formed by cutting of scissor tools. Scissor or Bent Shears, typically as the length of mandrel fulfill the roving strand mat on it until the number of layers end and handy to have available in case any glass cutting needs to be performed. The bent shears usually have a very sharp knife edge. A basic utility or razor knife may also come in handy for the same purpose.

Funnels are handy for pouring polyester safely into smaller containers when larger buckets are not being used. Transparent measuring containers of several sizes are useful for measuring polyester and gelcoat. A weight scale is an alternative for measuring small amounts of gelcoat and polyester, and also for weighing fiberglass. A variety of syringes can be used for correctly measuring very small amounts of hardener. A typical cap from a soda bottle can usually hold around 8ml of hardener. The gasket used to fill the gap between two half split pipe to control the matrix did not exit from the mold and to clamped properly And air vent are provided at suitable locations in the mold for allowing the volatiles and trapped air from the part of the outer split pipe through whole parts of mold that clamped the mold with bolt and nuts, when rotate in lathe machine at recommended speed that the air inside from mold are start to release se from mold.

Rubber mallets are useful for careful tapping of molds to help with demolding. A regular hammer is more useful for driving in wooden wedges inserted around the edge of the mold. Combination wrenches are used for mounting bolts and nuts on the fender and with cleats, eye bolts and U-bolts. A spanner (adjustable wrench) is also handy for holding bolts and nuts during tightening. The preparation of pipes for stacking of the fiber over the mandrel of starting and ending sheets could be fix by scotch and plaster used for spilt mold covering the resin do not impregnated out of the mold and labelling the number of products for code of experimental tests. Gloves may be required by bonders to prevent skin exposure to chemicals.

### **3.4.1 Mandrel**

**Core mandrel:** - is steel mandrel solid shaft used for winding the chopped strand mat and plain woven roving glass fiber warp 5 and 7 layers on mandrel to made hollow pipes. The manufacturing process of steel mandrel with 41mm diameter with 700mm long cutting by using power hack saw machine, and then turning it up to the diameter equals to 41mm ,the supporter both side ends

diameter 25mm and 50mm long at center to clamped form head stock and tailstock of lathe machine. Finally, the steel mandrel shaft dimension dia.41mm and length 600mm has been used for fabrication of pipe size and shape.

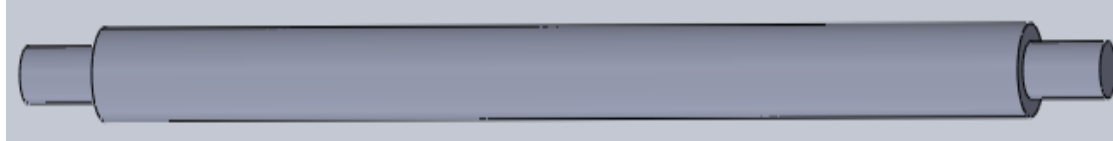


Figure 3.23 Core mandrel shaft

### 3.4.2 Outer split mold

The outer split mold have two half split parts are upper (cone) and bottom (drag) for using loading and un-loadings of the desire FRP pipe products. It used to make the outer diameter thickness pipes and uniform impregnations of resin through the layers and prevent to minimize the wastage of matrix for rotational speed on lathe machines. The outer two half mold manufactured from sales from the standard steel tube with that have internal diameter equal to reinforcement thickness diameter 54mm with 4 mm thickness cuts by grinder with a length of 600mm. the split in two half by using grinder cutting manually and the both side have sheet plate with 4mm thickness and 600mm long in two half edge of cone and drag from each have 4 holes with diameter of 13mm in 100mm apart from one to other sheet plate of mild steel, after that each must welded in each edge of four split tube by using welding machine. The Upper and Lower split mold Assembled by using welding machine to form outer mold that illustrated blow.

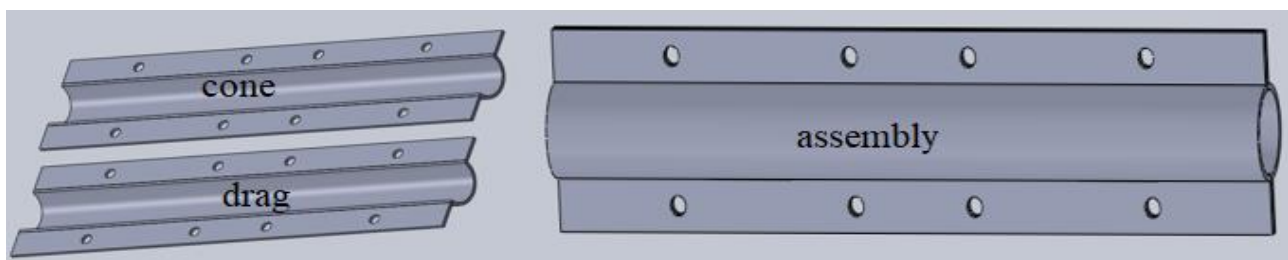


Figure 3.24 Outer split mold

#### 3.4.2.1 Fixed and closed cup

The fixed cup used to fixes mandrel and outer split mold welded with one side of it and other side of mandrel after used for purring required amount of resin closed the contrived mold by closed cup and the rest loading and unloading clamped with holes using bolt and nuts.

### 3.4.2.2 Bolt and nut

The bolt and nut clamping of the core wound roving sheet like layers and fiber with in upper and lower outer split mold for easy loading and unloading to remove the product and clamped by using 8 bolts and nuts of diameter 13mm selected from standard.



Figure 3.25 Bolt and nuts

### 3.4.2.3 Release agent

Release agents are usually functional used to prevent other materials from bonding to surface of molds or tool in a separate designated area as they can act as contaminate if accidentally incorporated into the composite lay-up. The mandrel is easily releasing the pipe free form contamination and it need surface smooth by using oils painting the whole surface. The split mold half parts are loading and unloading by bolt and nut for fix the floating during rotation of filled product of FRP pipe to be made. The wrench are used to open and closed the spilt mold and the demolding of the material from the contrived mold easily. The preventing from sticking to the outer mold and mandrel of desire product of GRE pipe. For this experiment is used mold release wax and releases agents are utilized in industry which are: plastic sheet, spray releases, release films and internal mold releases (added to gel coat or resin system)



Figure 3.26 Releasing wax gelcoat and plastic sheet film

### 3.4.3 Conventional lathe machine

The lathe machine used to rotations of reinforced fiber with matrix composition in low, medium and high speed of machine for uniform impregnation of unsaturated polyester resin through the

whole parts of fiber layers that would and fixed by using a clamped mold type of desire products overcome to fabricate FRP pipes. From the lathe machines tail stock dead center of carriage dimension space have height 17cm, the wide space 14cm and overall length of carriage space between headstock to tail stock have 3m space are available. The experimental products are manufactured in lathe machine with speed of 340 rpm and 625 rpm after the reinforcement and matrix purred in to the mold clamped time duration time as the gel time of mixed matrix have 8mm – 20 min started the CW rotation of machine in 20 min for plurality of resin pipes to manufactured.



Figure 3.27 Conventional lathe machine

The machine used for casting the UP resin mixing of it properly as the time span end to flow the fluid of matrix depends on the amount of hardener of 2% added to the composition. The mold inserted between the head and tail stock clamped as the time end to post curing time spent for 24 hours. The de-molding to remove the product of GRP pipe and secondary process are applied like trimming and cutting operation on both side of mold.

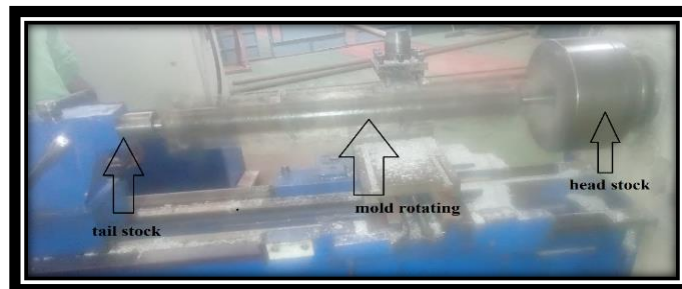


Figure 3.28 Rotation of mold using lath machine

The convectional lathe machine operation that used in three rotational speeds are 340 and 625 rpm parameter in time duration of 20 min for chopped and woven reinforcements have 7 layers used as several experimental product testing samples must be manufactured. So, the basic uses of lathe machine for proper impregnation resin accurate embodiment of layers with several speed rotation on it.

Table 3.7 Spindle speed of lathe machine for FRP pipe products

No experiment	Convectional lathe machine speed (rpm)		Time duration (min)
	340	625	
CSM	5 layers	7 layers	20 min
PWR	5 layers	7 layers	20 min

### 3.5 Method of data analysis

This session perform the reinforcement glass fiber sheet size would can be calculated which have 5 and 7 number of layers of chopped and woven roving mat glass and the unsaturated polyester resin matrix required amount also computed with respect to fiber weight.

#### 3.5.1 Reinforcement pallet size analysis

The glass fiber sheet like material has been used to fabricate the FRP pipe which forms like chopped strand mat and woven roving layers. The reinforcement layers, rolling on mandrel to form 5 and 7 layers of chopped strand mat and woven roving and the pipe hollow internal diameter was fixed that selected from a standard FRP pipe. However, the FRP pipe differs with the thickness depends on winding layers and amount of resin.

Availability of chopped and woven mat fibers is limited in our country and it's not all products are available in all regions and additional weights and widths are available upon request. Packing of the desire pipe products is illustrated below. Roll diameter can be computed with its number of layers becomes, internal diameter is 40mm and thickness of seals E-glass fiber in a form of chopped and woven mat is 0.5 mm and the length of the mandrel for manufacturing GRP pipe is 600mm.

Perimeter of rolling mandrel=  $\pi D$ , diameter increase with thickness of layers

$$\text{for 5 layers} = \pi(40 + 40.5 + 41 + 41.5 + 42) = 644\text{mm}$$

$$\text{for 7 layers} = \pi(40 + 40.5 + 41 + 41.5 + 42 + 42.5 + 43) = 912\text{mm}$$

Table 3.8 Rectangular size of glass fiber sheet required for rolling

	Types of reinforcement			
	Chopped strand mat		Woven roving, mat	
No of layers	5	7	5	7
Pallet size (mm)	644×600	912×600	644×600	912×600

Each roll is wound on 40 mm of mandrel shaft and placed inside an unsaturated polyester resin bag and loading in split mold. And it rotates on lathe machine with 20 min for uniform

impregnation of mixed fiber and resin. After that the boxed product is then placed horizontally on wounded pallet and shrink wrapped for stability and protection. Labelling each roll bears detailing the product description, product code, nominal weight, and roll width, and roll number, date of manufacture and time of manufacture.

Both of reinforced fibers measured by using weight scale for volume fractional analysis can be calculation used for percentage of matrix amount determinations and weight it up resin.

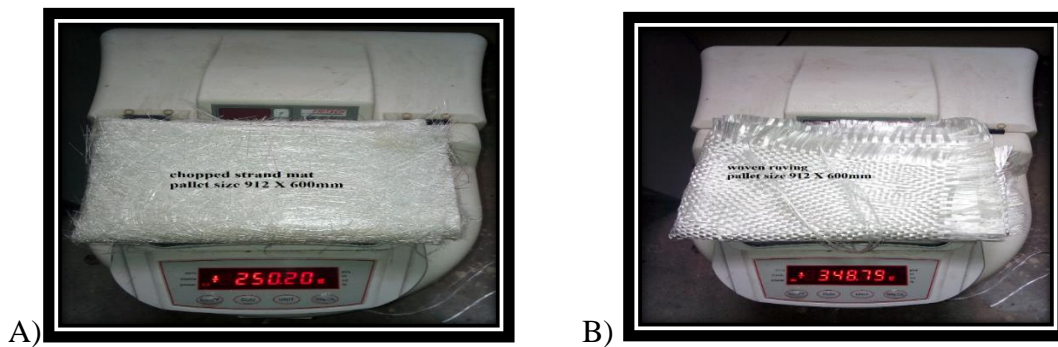


Figure 3.29 A) Chopped strand mat weight and B) woven roving

### 3.5.2 Composite data analysis

The fiber glass of chopped and woven laminates must be considering the following.

- ❖ Measure catalyst accurately and stir thoroughly into Resin, wearing appropriate
- ❖ A Catalyst dispenser is ideally required for accurate measuring.
- ❖ The cure of the resin will begin as soon as the catalyst is added, and the speed of the reaction will depend upon the particular resin and activity of the catalyst.
- ❖ Once the resin starts turning to a jelly like consistency, you must immediately stop laminating and clean your tools, finishing off your immediate area.
- ❖ If adding pigment do so first and thoroughly stir in mixing well before adding catalyst, be careful not to under or over pigment [22].

Estimating Resin to Fiberglass ratios – These are approximations and for guideline use only, variations/complexity of laminate/mold surface may alter quantities slightly. Form several literatures conducted the ratio compositions of chopped strand mat have 2 up to 2.5 and woven roving 1 up to 1.5 time of thermo-setting matrix material [53]. Then amount can be calculated as 1 gram of CSM required 2.17-gram UP resin and 1 gram of PWR need 1.2 gram of UP resin for this proportionality the required amount of matrix illustrated below.

Table 3.9 weight of chopped strand mat and woven roving of 5 layers

-	Fiber		Matrix						Total	
			UP resin		MEKP (2%)		Combined		CSM	PWR
	CSM	PWR	CSM	PWR	CSM	PWR	CSM	PWR		
Mass (gram)	179.1	249.14	387.5	299	7.75	6.0	395.25	305	574.35	554.14
Density (g/cm <sup>3</sup> )	2.60	2.60	1.125	1.125	1.08	1.08	1.14	1.14	-	-
Volume (cm <sup>3</sup> )	68.88	92.82	344.44	265.78	7.18	5.56	346.71	267.54	415.59	360.36

Table 3.10 weight of chopped strand mat and woven roving of 7 layers

-	Fiber		Matrix						Total	
			UP resin		MEKP (2%)		Combined		CSM	PWR
	CSM	PWR	CSM	PWR	CSM	PWR	CSM	PWR		
Mass (gram)	250.20	348.79	542.1	418.55	10.82	8.37	552.92	426.921	803.12	775.71
Density (g/cm <sup>3</sup> )	2.60	2.60	1.125	1.125	1.08	1.08	1.14	1.14	-	-
Volume (cm <sup>3</sup> )	96.15	134.15	481.87	372.04	10.02	7.75	491.89	379.79	588.05	513.94

### 3.5.3 Fiber volume fraction analysis

Fiber reinforced material is distributed throughout the matrix in a pattern we could describe as somewhat repeating or periodic. Assume that either of the two models represents to a reasonable degree of accuracy the microstructure of a fiber reinforced composite material. By directing the attention to a unit cell of that model we easily see that the cross-sectional area of the fiber relative to the total cross-sectional area of the unit cell is a measure of the volume of fiber relative to the total volume of the composite. To calculate the values of volume fraction of the fiber and matrix and composite materials as shown below [11]. The calculate of volume fraction of fiber reinforced plastic computed as,

- Volume fraction of fiber ( $V_f$ ) = 
$$\frac{\text{volume of fiber } (V_f)}{\text{volume of composite } (V_c)} \quad (3.1)$$

- Volume fraction of matrix ( $V_m$ ) = 
$$\frac{\text{volume of matrix } (V_m)}{\text{volume of composite } (V_c)} \quad (3.2)$$

From, Conley's Quality Assurance program is certified to ISO 9001-2008. The FRP pipe dimension taken from Conley specification standard. And its fittings are inspected at each stage of manufacture for liner, reinforcement and external corrosion barrier thickness listed below [5].

Table 3.11 FRP pipe nominal dimensional data

Nominal pipe size (mm)	Outer diameter (mm)	Inner diameter (mm)	Total wall thickness (mm)
25.4	33.5	26.6	3.6
37.65	47.8	40.6	3.6
50.8	60.5	52.3	4.1
76.2	88.9	78.0	5.5
101.6	114.3	102.3	6.0
152.4	168.3	154.1	7.1
203.2	219.1	202.7	8.2

The manufacturing of FRP pipe having the following dimension based on the above standard table based on its dimension selected could be designed and fabricate in the figure illustrated below.

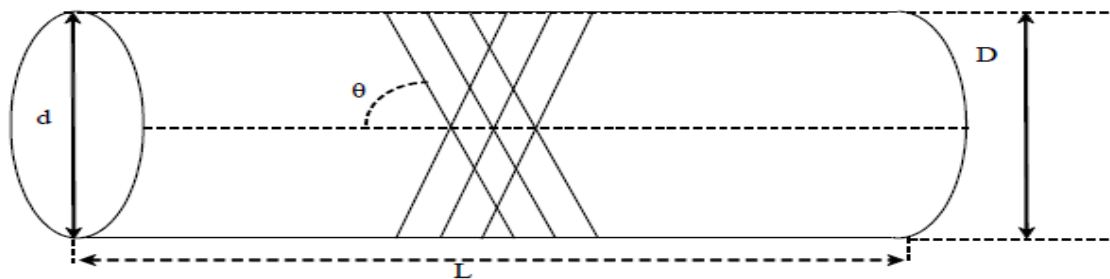


Figure 3.30 Dimension of FRP composite pipe [5].

From table 5 above, the nominal diameter of FRP pipe 1.5 inch (37.65 mm) have been selected, and then the FRP pipe can made with the following internal diameter (d) that taken from above standard table is 40.6 mm and the outer split mold diameter is equal to 54mm.

Total volume of FRP pipe composite ( $V_c$ ) can be calculated as,

$$\begin{aligned} \text{Area} &= \text{outer area} - \text{core area} = (\pi r_o^2) - (\pi r_i^2) = \pi (r_o^2 - r_i^2) \quad (3.3) \\ &= \pi ((27)^2 - (20.3)^2) = \pi (729 - 412.09) = 995.09\text{mm}^2, \end{aligned}$$

And length of pipe =600mm (Assume L= 600mm)

$$\begin{aligned} \text{Volume of composite, } V_c &= 995.09 \times 600 = 597058.44\text{mm}^3 \\ &= 597.0584\text{ml} \quad (1\text{ml}=1000\text{mm}^3) \end{aligned}$$

The space between the mandrel up to internal diameter of split mold of composite volume have 597.058 ml. The mechanical properties of a composite are strongly influenced by the proportions and properties of the matrix and the fibers. The commonly used method in expressing constituents'

proportions is by volume fraction. The fiber reinforced polymers consist of the fiber and the matrix; thus the fiber volume fraction is defined as the ratio of the volume of fiber to the total volume.

$$\text{Fiber volume fraction of, } V_f = \frac{w_f/\rho_f}{\left(\frac{w_f}{\rho_f}\right) + w_m/\rho_m} \times 100, \quad (3.4)$$

The weight of fiber for seven rolling layers of chopped strand mat and woven roving mat are measured from their pallet size of each fiber on weight measuring equipment and the calculation fulfills the table below. And the amount of matrix can be calculated by the following formula,

$$V_m = 1 - V_f \quad (3.5)$$

And the CSM and PWR composition ratio can be calculated as follows,

$$\text{the chopped strand mat volume fraction} = v_{CSM} = \frac{w_{CSM}/\rho_{CSM}}{\left(\frac{w_{CSM}}{\rho_{CSM}}\right) + w_m/\rho_m} \times 100 \text{ and}$$

$$\text{the woven roving mat volume fraction} = v_{PWR} = \frac{w_{PWR}/\rho_{PWR}}{\left(\frac{w_{PWR}}{\rho_{PWR}}\right) + w_m/\rho_m}$$

Table 3.12 Weight composition of FRP pipe

<i>Composition</i>	<i>Pallet size</i>	<i>Chopped strand mat %Wt</i>	<i>Woven roving %Wt</i>	<i>Matrix %Wt</i>
- CSM/ CSM/ CSM-	912 × 600	16.56	---	83.44
-PWR/ PWR/ PWR-	912 × 600	---	26.37%	73.63

Therefore, volume fraction of fiber depends on the composition of reinforcement glass fiber with matrix that computed in above composition though out the surface of the product. Due to the embodiment of pipe that have the unsaturated polyester resin impregnated the whole parts of surface with the injection ports process of lower viscosity resin and the preparation to make the FRP pipe manually within lathe machine different rotational speed distributed the resin through roved layers of fibers.

### 3.5.4 Void content analysis

Theoretical calculations for strength, modulus, and other properties of a fiber reinforced composite are based on the fiber volume fraction in the material. Experimentally, it is easier to determine the

fiber weight fraction  $W_f$ , from which the fiber volume fraction  $V_f$  and composite density  $\rho_c$  can be calculated.

$$\text{Composite density, } \rho_c = \frac{1}{w_f/\rho_f + w_m/\rho_m} \text{ or } \rho_c = \rho_f \times v_f + \rho_m \times v_m \quad (3.6)$$

Density of composite chopped strand mat ( $\rho_{CSM}$ ) =  $\rho_{CSM} \times v_{CSM} + \rho_m \times v_m$  and Density of woven roving mat ( $\rho_{PWR}$ ) =  $\rho_{PWR} \times v_{PWR} + \rho_m \times v_m$ . A high void content (over 2% by volume) usually leads to lower fatigue resistance, greater susceptibility to water diffusion, and increased variation (scatter) in mechanical properties. The void content in a composite laminate can be estimated by comparing the theoretical density with its actual density:

$$v_v = \frac{\rho_c - \rho}{\rho_c} \times 100 \quad (3.8)$$

Where,  $\rho_c$  = theoretical density, calculated from equation above,  $v_v$  = volume fraction of voids,  $\rho$  = actual density, measured with experiment on composite specimens (which is less than  $\rho_c$  due to the presence of voids).

Table 3.13 Density and Void content percentage of FRP pipe

Composition	Composite density ( $\rho_c = \text{g/cm}^3$ )	Measured density ( $\rho_m = \text{g/cm}^3$ )	Void content (%)
5 CSM	1.247	1.174	5.85
7 CSM	1.387	1.215	12.40
5 PWR	1.503	1.368	8.98
7 PWR	1.526	1.343	11.99

## Chapter four

### Result and discussion

#### 4.1 Introduction

The process of manufacturing FRP pipe with hand rolled of chopped strand mat and woven roving layers using a mandrel shaft manually operating system on working table and then purring UP resin. When this thesis held on the strand mat layer in a form of chopped and woven roving sheet rolls dry winding on a mandrel shaft and purring a mixed matrix by funnel in a port on mold and then rotates it on lath machine uniform embodiment. The results have been four kind of sample are 5 CSM, 7CSM, 5PWR and 7 PWR layers fabricated and experimental analysis of mechanical test of each specimen. Based on the nature of glass fibers that the strand mat and roving number of layers and the fabrication of layers amount of fibers that made it sheet like material leads to the mechanical properties improved and matrix distribution process through the surface of round layers.

#### 4.2 Compression test analysis

Fiber reinforced composite materials consist of high strength and high modulus fibers embedded in or bonded to a matrix with distinct interfaces between them. In general, fibers are the principal load-carrying members while the surrounding matrix keeps them in the desired location and orientation, and acts as a load transfer medium between them. Compressive strength decreased as the covering filament spacing increased, suggesting that the shorter the filament spacing, the higher the resistance force against compressive load. Not all the materials are strong in compression several materials, which are good in tension, are poor in compression. Many materials poor in tension are good in compression. During the test, for ASTM standard the specimen is compressed and deformation Vs stress the applied is recorded. Compression test is just opposite in nature to tensile test. Nature of deformation and fracture is quite different from that in tensile test. Compressive load tends to squeeze the specimen and the brittle materials are generally weak in tension but strong in compression. The compression testing of fiber-reinforced composites per ASTM D2412 the length of specimen has 150 mm of FRP pipe, is used to determine mechanical material property data that are of interest for design specification and quality control.



Figure 4.1 FRP pipe compression tested samples

The compressive strength tested specimen can be described by the graph illustrated below with average of two sample. When the layers increase to roll the pipe leads to rise the compressive strength and the chopped strand mat sheet are approximately equivalent with the woven roving layer product as seen the graph below in figure 4.2 and the woven type of FRP pipe products have high strength than chopped strand mat layers of pipe which have  $19.04 \text{ N/mm}^2$  of 7 layers and the 7 layer of chopped mat have  $15.93 \text{ N/mm}^2$  the second most compressive strength.

Table 4.1 Compressive strength test result

<b>Samples</b>	<b>Trial 1 (N/mm<sup>2</sup>)</b>	<b>Trial 2 (N/mm<sup>2</sup>)</b>	<b>Average value (N/mm<sup>2</sup>)</b>
5 CSM	5.65	7.39	6.52
7 CSM	17.39	14.46	15.93
5 PWR	7.52	9.54	8.38
7 PWR	19.22	18.86	19.04

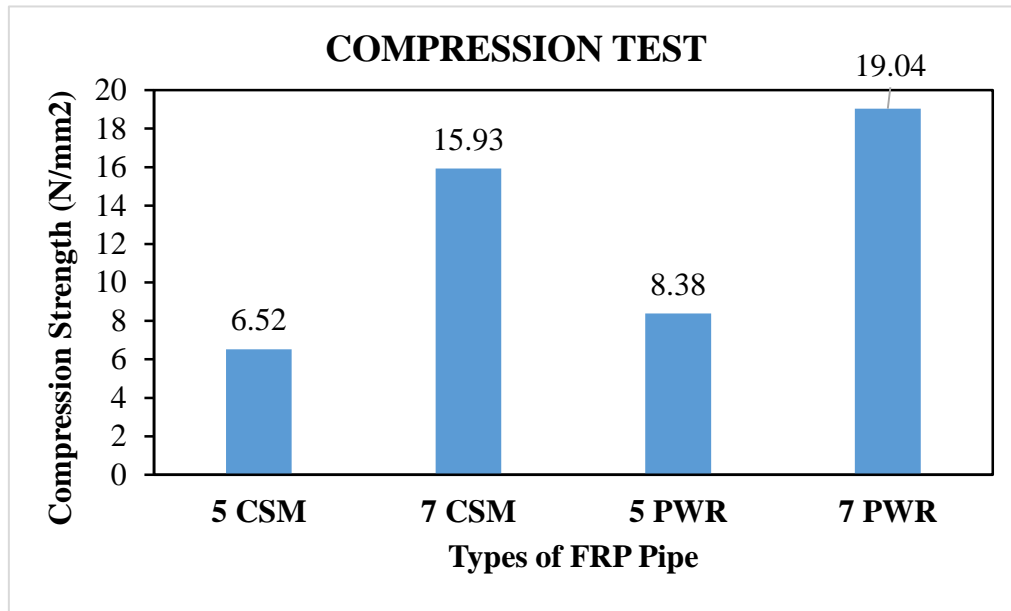


Figure 4.2 result graphs of compressive strength

### 4.3 Hardness test analysis

The curing of FRP pipes can be tested by Vickers hardness with 3kg machine of the following four specimens carried out in material science and engineering laboratory in ASTU. Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. However, the term hardness may also refer to resistance to bending, scratching, abrasion or cutting. Hardness value of CSM and PWR pipe are compared. The values of PWR pipes are showing better than CSM pipe hardness. This indicates that the PWR pipe can used in similar conditions of CSM pipe usage.

Table 4.2 Micro hardness test result

Samples	Trial 1(HV)	Trial 2(HV)	Trial 3(HV)	Average(HV)
5 CSM	30.1	25.6	39.5	31.73
7 CSM	38.1	40.9	46.4	41.80
5 PWR	59.5	54.3	48.5	54.10
7 PWR	64.1	58.5	72.2	64.93

By using micro soft excel the graph of hardness tested result illustrated below that have the woven roving layers more dens than the chopped strand mat layers and when the number of layers increased the hardness also increases.

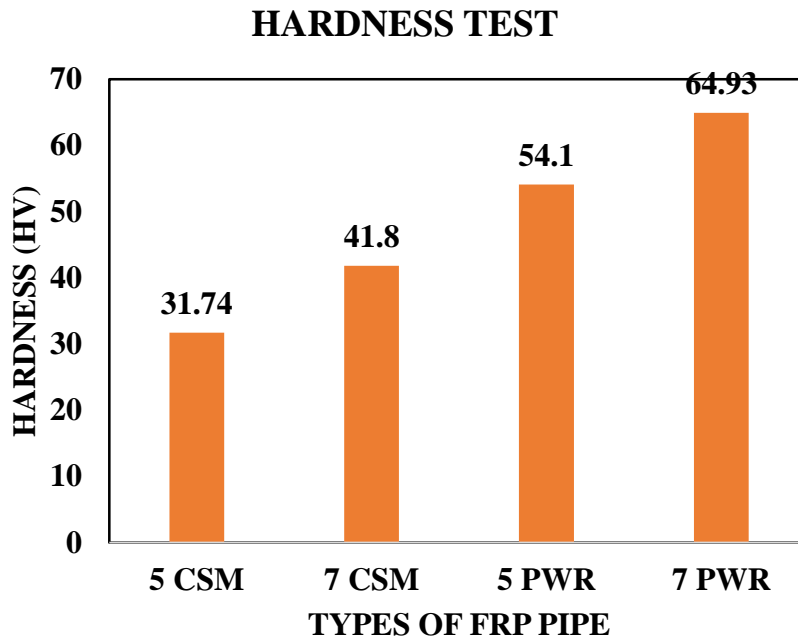


Figure 4.3 result graphs of Vickers hardness

#### 4.4 Water absorption test analysis

The result can be measured form 1 up to 7 days that the sample immersed on water the result given as the following result illustrated as a graph. The result in figure below shown that the water absorption of specimens almost increases with immersion time at the starting stage and later keeps less water absorption does not change significantly. Generally, the PWR pipes exhibit large water absorption due to the presence of more micro void content at the embodiment of reinforcement with UP resin interface.

Table 4.3 Water absorption test in weight immersed up to 7 days

Immersion time (Hr.)	FRP pipes measured in weight (gm)			
	5 CSM pipe	7CSM pipe	5PWR pipe	7PWR pipe
<b>0</b>	9.70	10.16	8.08	9.25
<b>24</b>	9.83	10.35	8.42	9.57
<b>48</b>	9.97	10.50	8.70	9.73
<b>72</b>	10.02	10.59	8.99	9.99
<b>96</b>	10.13	10.67	9.13	10.16
<b>120</b>	10.25	10.78	9.17	10.29
<b>144</b>	10.32	10.87	9.20	10.55
<b>168</b>	10.38	11.13	9.28	10.77
<b>Water absorption (%)</b>	7.01	9.54	14.85	16.43

The result in table shown above water absorption of the specimens almost increasing with immersion time at the starting stage and later keeps less water absorption after that water absorption does not change significantly. in the other way, water absorption of specimen immersed chopped strand mat made pipe have less water absorption than woven roving layers due to amount of resin required. As we can see in the graph the woven pipe has 16.43% of water absorption than other FRP pipes due to the presence of micro void at the reinforcement/matrix production process. And the chopped mat pipe having less amount of water absorption 7.01% and when the layers increases leads to increases water absorption for 7 layers rolled pipe have 9.54% rise of absorption. When the usage of FRP pipe of WRP pipe used for low moisture content as compared to CSM pipe.

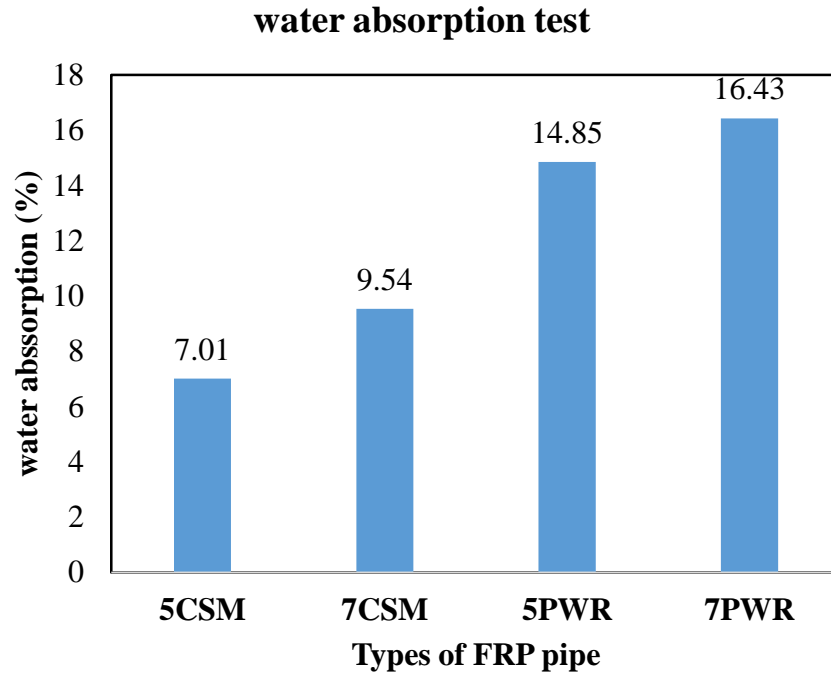


Figure 4.4 result graphs of water absorption

The chopped strand mat pipe material reinforcements in nature needs more amount of resin and it's have good embodiment with each other through the whole thickness. As the number of round and thickness also increases it rise the water absorption content for both the CSM and PWR pipe products.

## Chapter five

### Conclusion and recommendation

The FRP pipe that manufactured with in glass fiber form of CSM and PWR strand mat are implemented in hand rolling layup method by using mandrel and outer split mold design and fix it on lath machine for 5 layers speed 340 rpm and 7 layers speed 625 rpm at 20 min time duration to gel the UP resin in whole part of roved layer embodiment build up uniformly throughout the length and diameter of pipe. As conducted the relevant experimental result of FRP pipe samerized the mechanical properties of each type with compression and hardness test result are verified below.

#### 5.1 Conclusion

The FRP pipe fabrication in the least cost of production as compared to filament winding method and it also reaches in few years for production within low investment cost. So utilizing this fabrication techniques the eco friend of production methods for one of manufacturing process in future work can aid the environment as well as the country by reducing the expense needed for imported FRP pipes form worldwide industries. The CSM and PWR pipes materials carried out in this study also shows, good mechanical properties and the tendency to replace other production techniques that having higher investment needed. Depends of the production type of FRP pipes the following summarized conclusions are made below.

- The plain woven roving (PWR) pipe material shows better hardness value as compared to chopped strand mat (CSM) pipe this is because of the strength of mat sheet layers of fiber having reinforcement type and numbers of layers rolling as well as the amount of matrix material (UP resin) needed.
- The chopped strand mat glass reinforcement layer materials have low mass and needed high UP resin matrix embodiment of FRP pipe that leads to low hardness and when increased the rolling layers rise the dens strength of CSM pipes.
- When the spindle speed of lathe machine increases used to reduce the porosity of pipes as we can see on the OPM structures and the CSM pipe have more porosity than PWR pipes materials due to viscosity of UP resin flow impregnation the shorter (chopped) reinforcement type that influence flow of resin do to it had few minute of curing time.

- From water absorption of FRP pipes high water absorbed pipe has been the woven roving pipe (PWR pipe) affected by moisture than chopped fiber mat (CSM) pipe. And both fabricated FRP pipes affected by increasing the number of layer rolled and it leads to more water absorbed.
- The compression test of FRP pipes of woven roving pipe has high compressive strength than the chopped strand mat sheet layers and when increases the number of layers leads to increase the compressive strength of pipe. And the equivalent layer of two glass fiber sheet have similar proportional strength of material deformation.
- The chopped strand mat pipes has influenced by much amount of resin needed to made the product, due to twice of matrix required the compressive strength lower the that of the woven roving pipe material.

## **5.2 Recommendation**

The fabrication of components of steel mandrel shaft and outer split mold of cone and drag type closed valves in both sides as whole required equipment in production technique must be manufactured. For FRP pipes materials of products from contrived split mold method are eco-friendly's manufacturing methods from several fabrication of FRP pipes like filament winding Pultrusion, centrifugal casting etc. to reduce the initial investment and manufacturing cost of pipe and effective usage of matrix of UP resin.

In the same way many researchers conducted many works around the world on FRP pipe manufacturing by using filament winding method but here is supposed that the of raw materials used for the purpose production process of wastage are increase tremendously, the overall manufacturing cost also difficult and the desired products having same physical and mechanical properties. From this regard, it is possible to conclude that output of this FRP pipe material manufacturing method can be hopefully has potential to substitute dry filament winding techniques of productions of FRP pipes. As the sheet of glass fiber material properties the chopped strand mat reinforcement needed more amount of resin to impregnated the whole part embodiment that affect the strength of FRP pipe product, so when the usage of two kind of pipe relatively the woven roving layer have high strength property purpose due the fabrication of glass fiber sheet reinforcement and less amount of resin needed.

### **5.3 Future work**

From different aspects, the working of FRP pipes as glass fiber strand mat from chopped and woven types of composite have several advantages. From this point of views, regarding FRP pipes several; things can be made and improved in the future in which this study could not addressed. So the following thesis areas are raised as recommendation for future studies.

- ❖ To future for researchers those have willing to do the FRP pipe fabricated in chopped and woven roving mat can be also analysis on the following test has been consider for other purpose shall be testing like Hydrostatic pressure, Axial tensile strength, Hoop tensile (Burst) strength, Glass transition temp Differential, Strain corrosion, Hydrostatic Design Basis (HDB), Inter-laminar shear strength testing (ILSS), Long term stiffness & Creep factor, Impact resistance, Pipe Stiffness testing, creep test etc.
- ❖ By changed the fabrication process of FRP pipe using rolling machine, cutting tools and injection pumping for matrix material for purring resin. After molded the material set in different temperatures for gel and curing time of matrix material analysis.
- ❖ The manufacturing of FRP pipes also produced by using natural and synthetic fibers composition and hybrid of each reinforcement. And also used varies kinds of thermosetting resin.

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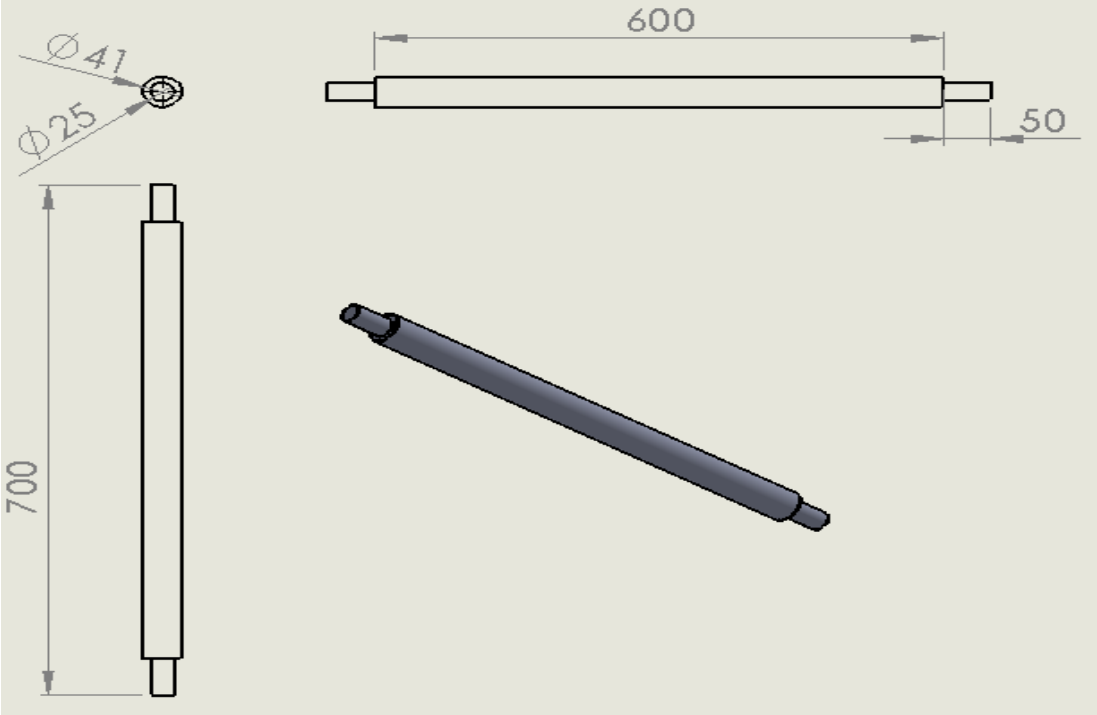
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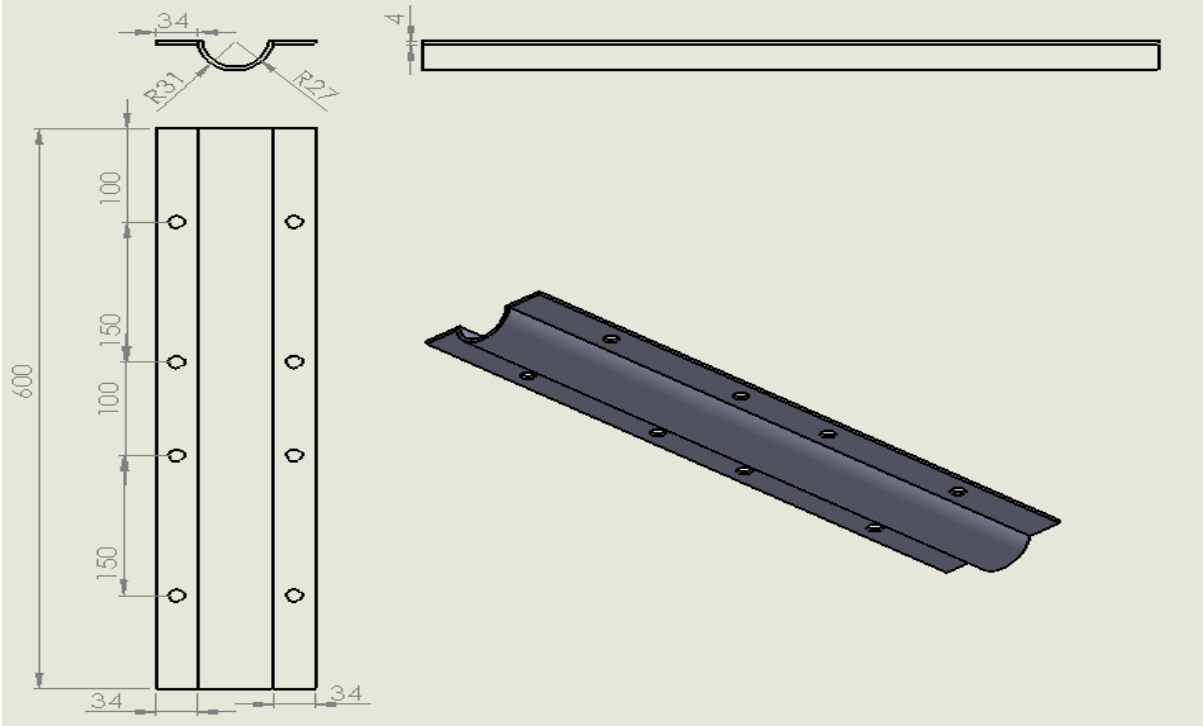
# Appendix

## Appendix 1 Mandrel

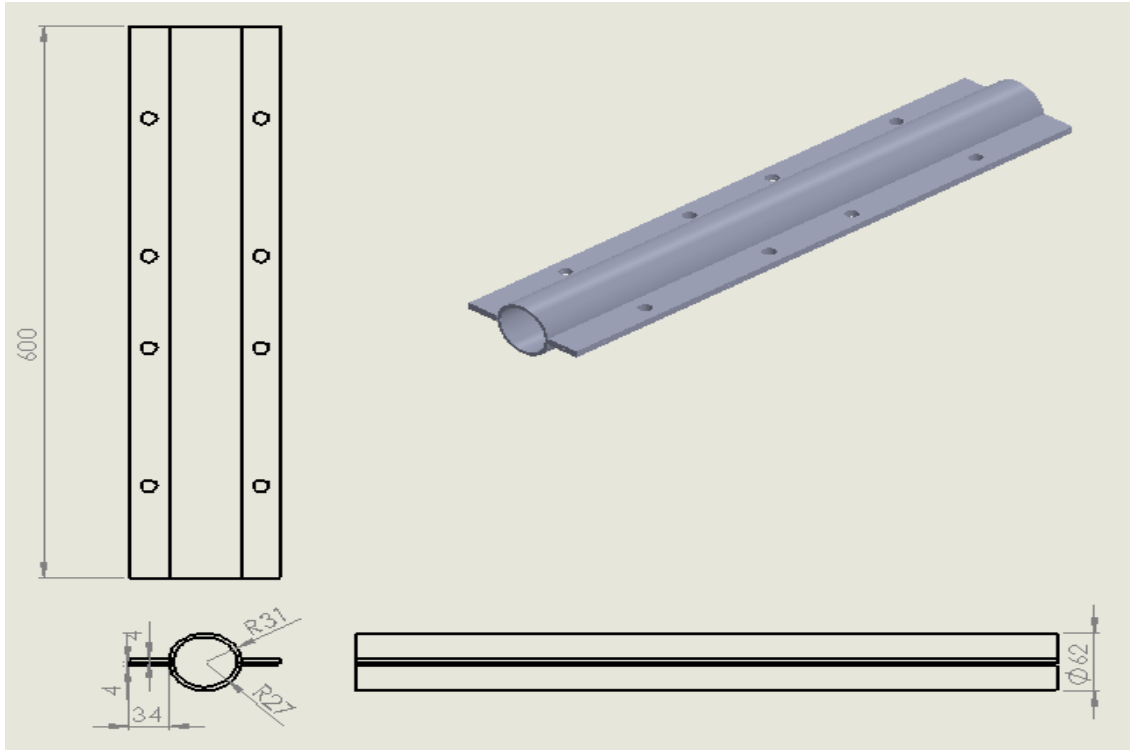


All dimension in mm

## Appendix 2 Halve of outer split pipe

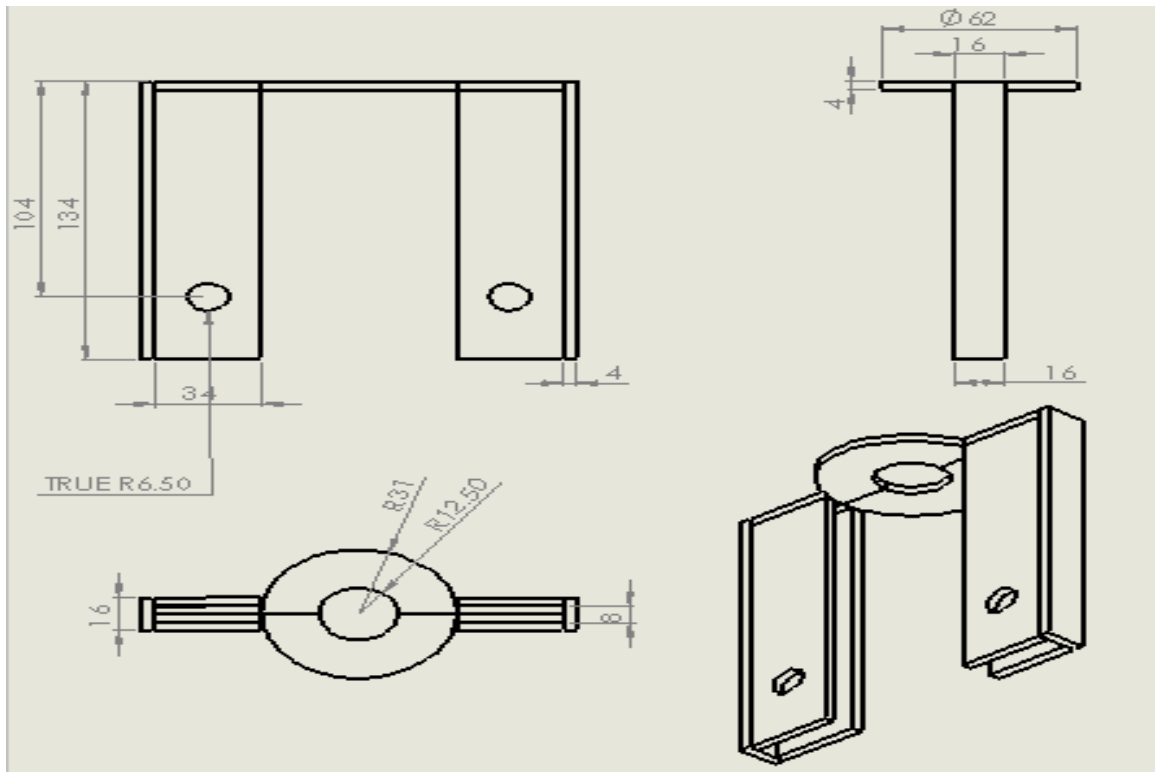


### Appendix 3 Assembly of split pipes

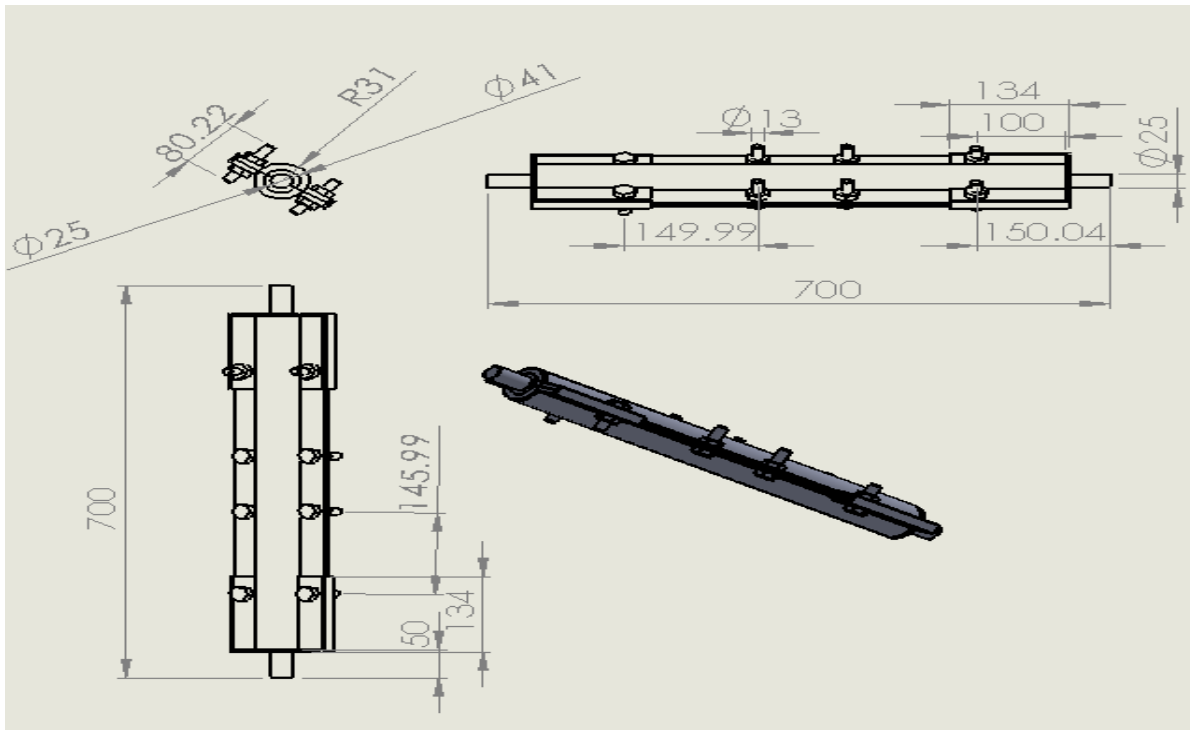


All dimension in mm

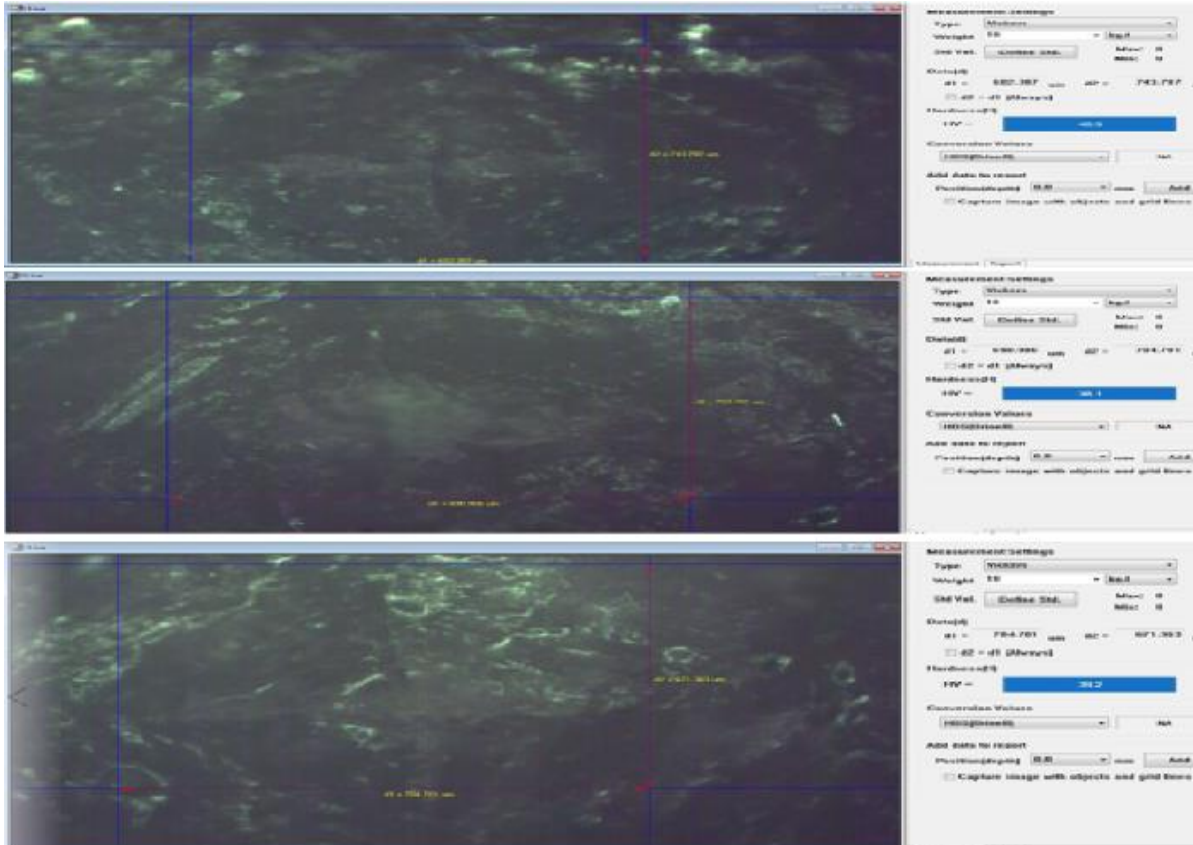
### Appendix 4 Caps for closed assembled split pipe



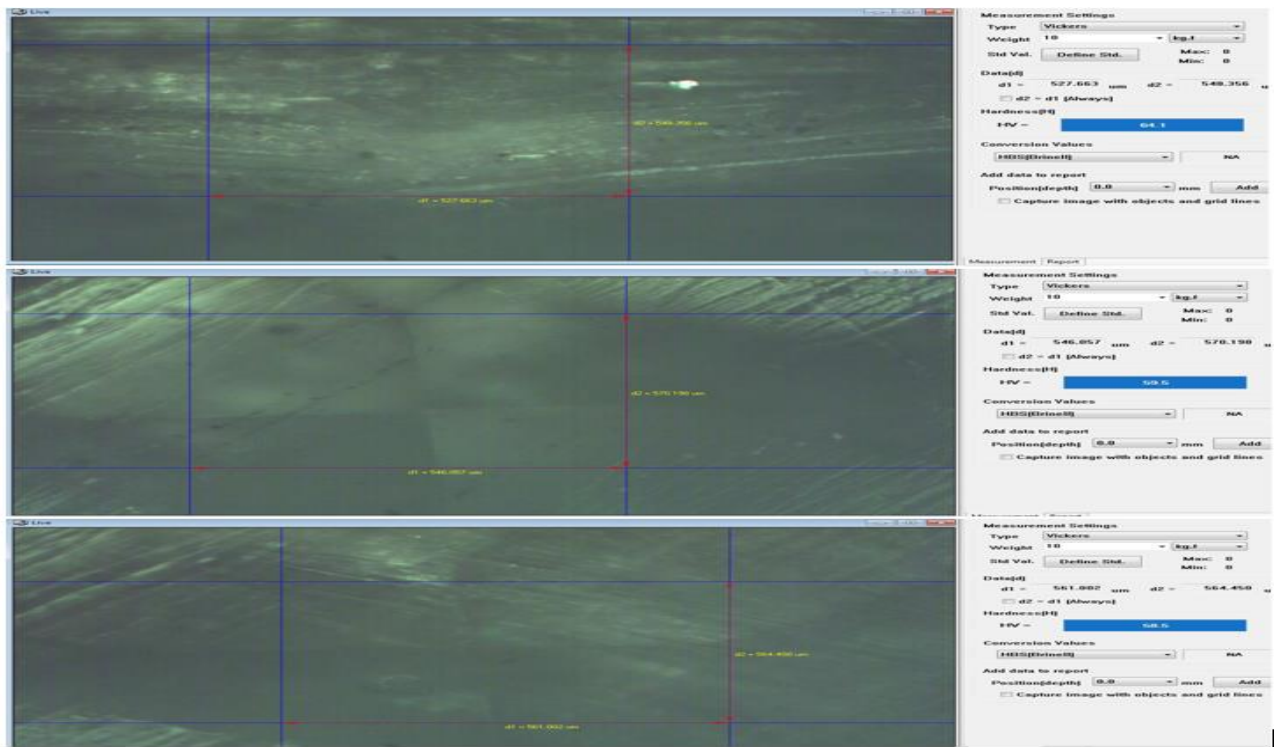
### Appendix 5 Contrived mold assembly



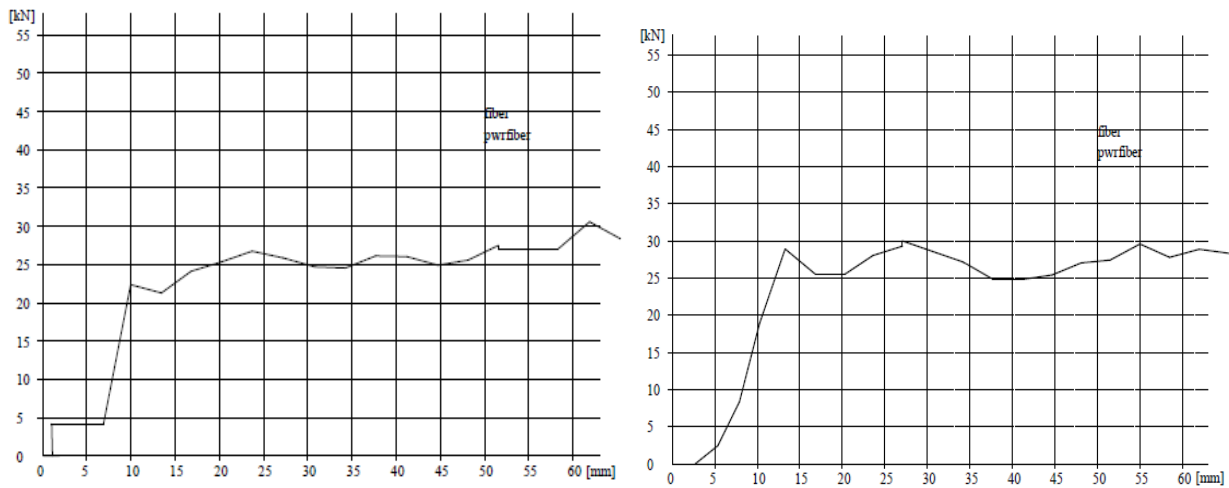
### Appendix 6 Vickers hardness tester machine of CSM pipe



## Appendix 7 Vickers hardness tester machine of PWR pipe



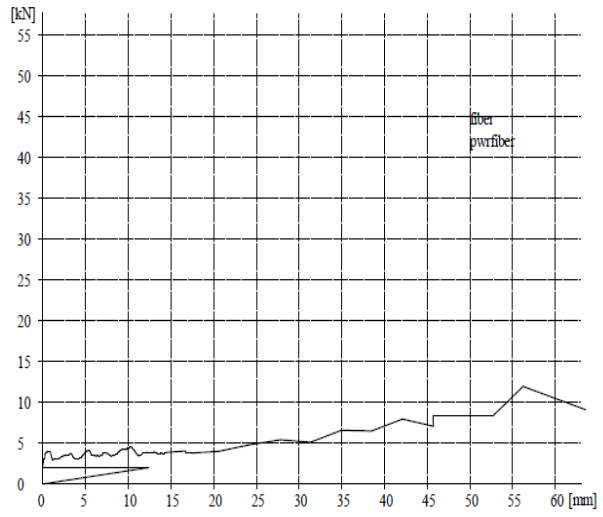
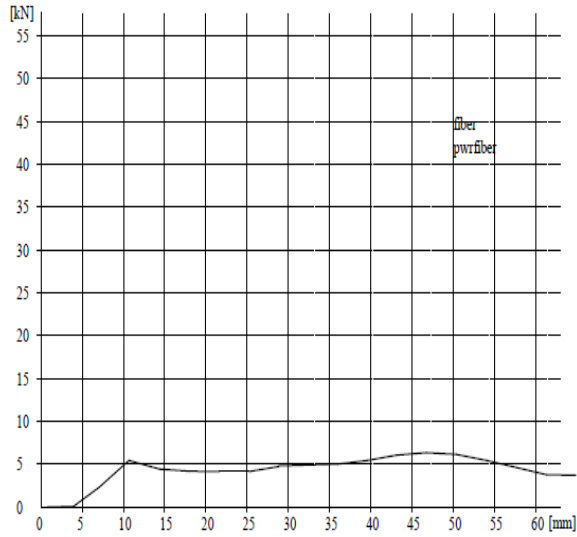
## Appendix 8 Force-elongation-diagram for tensile test specimen of PWR pipe



7 layers of PWR pipe sample 1

&

sample 2



5 layers of PWR pipe sample 1

&

sample 2

### Appendix 9 Stress-elongation-diagram for tensile specimen

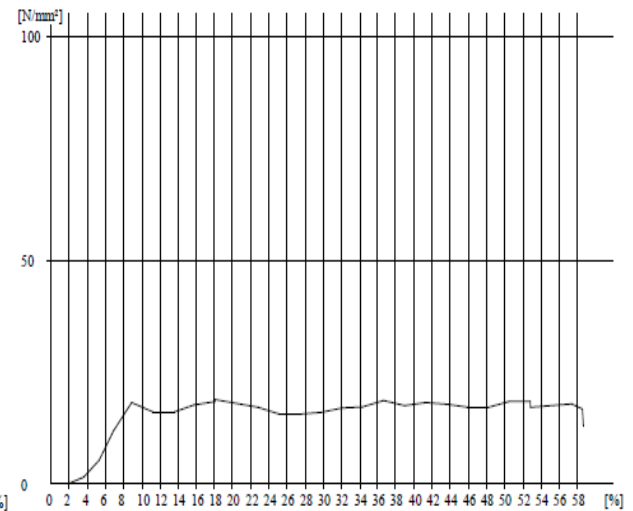
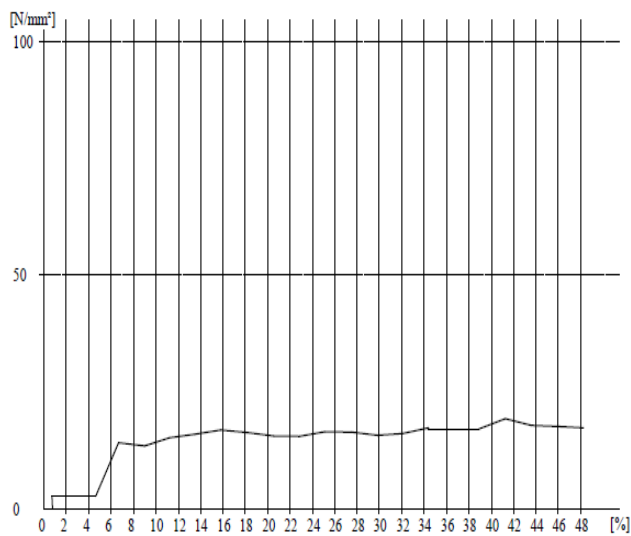
Material: glass fiber

Free Text: plain woven roving pipes

Initial measurement length: 150mm

Specimen diameter: 50mm

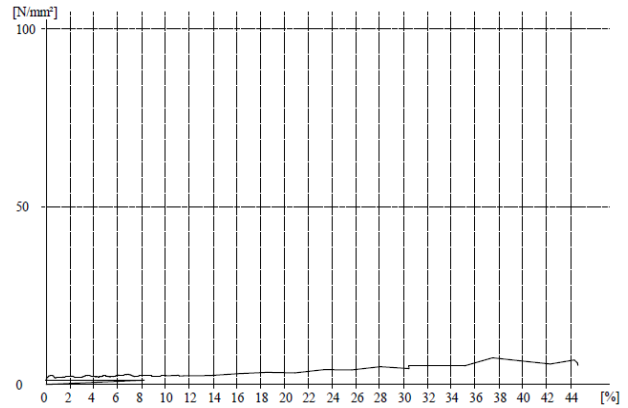
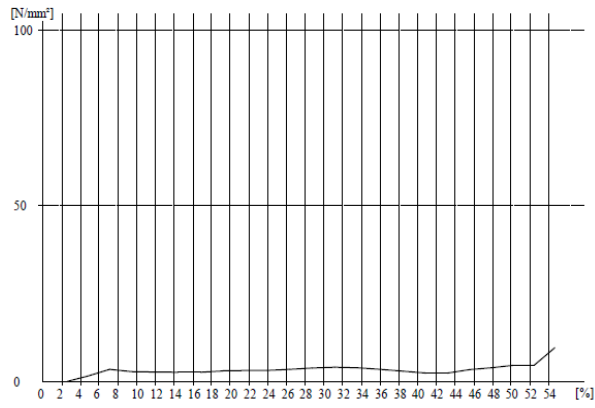
Date: 15.01.2020



7 layers sample 1

&

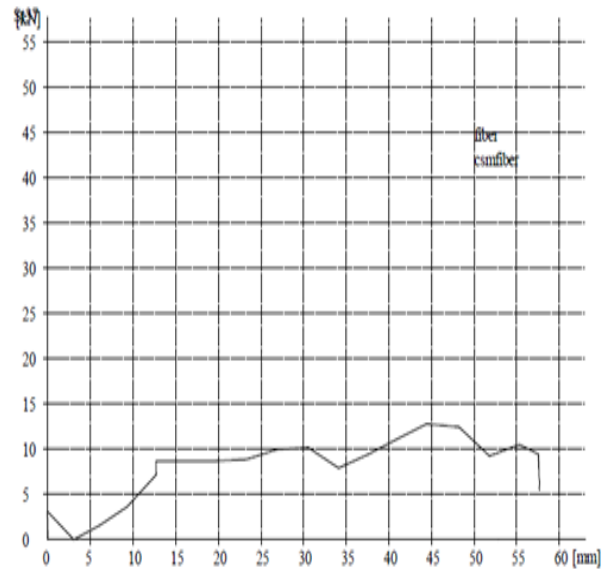
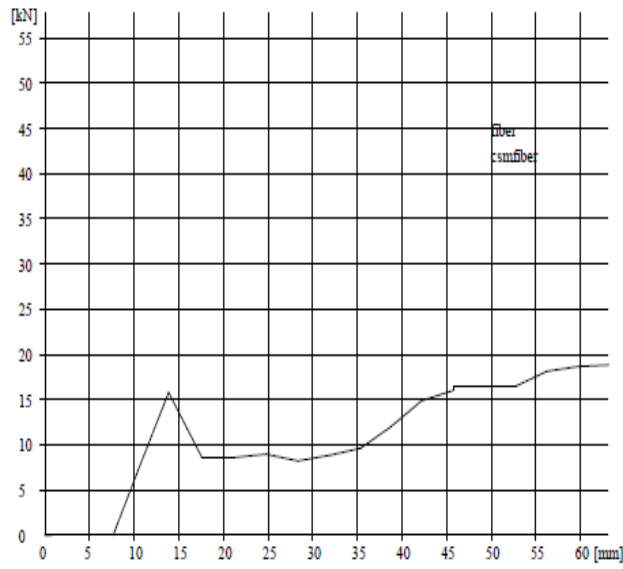
sample 2



5 layers sample 1

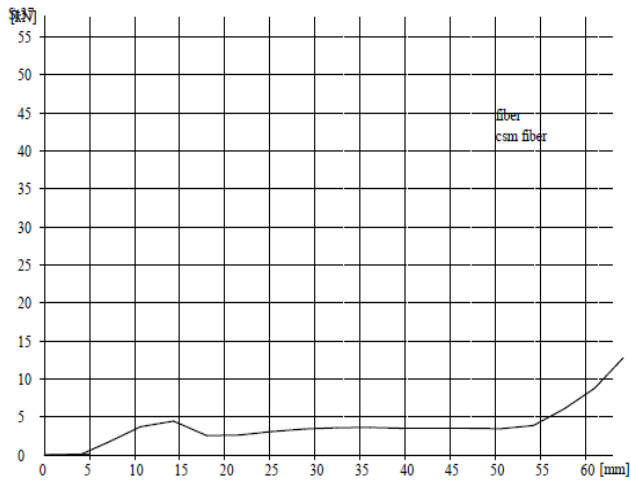
& sample

Appendix 10 Force-elongation-diagram for tensile test specimen of CSM pipe

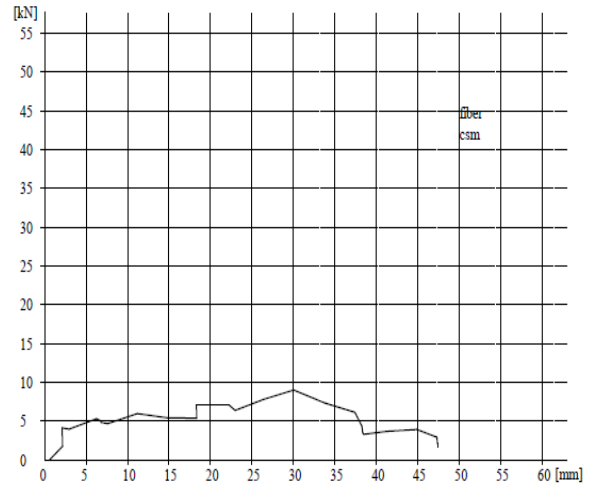


7 layers of sample 1

& sample 2



5 layers of sample 1



& sample 2

### Appendix 11 Stress-elongation-diagram for tensile specimen

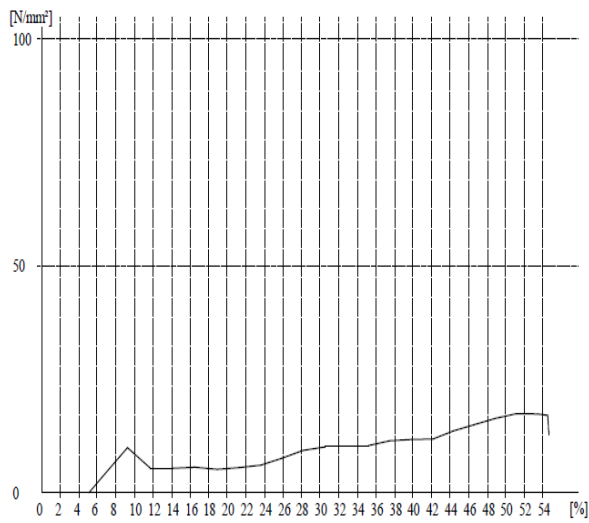
Material: glass fiber

Free Text: copped strand mat (5 layers)

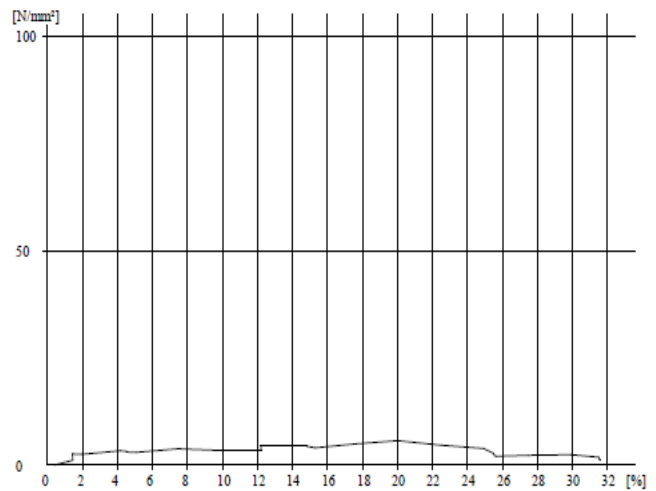
Initial measurement length: 150mm

Specimen diameter: 50mm

Date: 15.01.2020



7 layers of sample 1



& sample 2

Appendix 12 Output force-elongation-table

Material: glass fiber

Free Text: PWR 7 layers

Initial measurement length: 150mm

Specimen diameter: 54mm

Date: 15.01.2020

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.00	0.14
2	0.02	1.92
3	0.00	3.30
4	0.01	4.59
5	0.01	0.00
6	0.00	1.12
7	4.16	1.04
8	4.16	6.92
9	22.36	9.98
10	21.30	13.46
11	24.11	16.82
12	25.34	20.22
13	26.74	23.71
14	25.86	27.20
15	24.73	30.81
16	24.55	34.26
17	26.12	37.67
18	26.04	41.24
19	24.92	44.73
20	25.57	48.15
21	27.50	51.57
22	27.07	51.58
23	27.07	58.38
24	30.57	61.91
25	28.36	65.39
26	27.95	68.97
27	27.54	72.38

Appendix 13 Output stress -elongation-table

Material: glass fiber

Free Text: 5 PWR layers

Initial measurement length: 150mm

Specimen diameter: 50mm

Date: 15.01.2020

No.	S [N/mm <sup>2</sup> ]	E [%]
0	0.00	0.00
1	0.00	0.09
2	0.01	1.28
3	0.00	2.20
4	0.01	3.06
5	0.01	0.00
6	0.00	0.75
7	2.62	0.69
8	2.62	4.61
9	14.06	6.66
10	13.39	8.98
11	15.16	11.21
12	15.93	13.48
13	16.81	15.80
14	16.26	18.14
15	15.55	20.54
16	15.44	22.84
17	16.42	25.11
18	16.37	27.49
19	15.67	29.82
20	16.08	32.10
21	17.29	34.38
22	17.02	34.39
23	17.02	38.92
24	19.22	41.27
25	17.83	43.60
26	17.57	45.98
27	17.32	48.25

Appendix 14 Output stress -elongation-table

Material: glass fiber

Free Text: 7 CSM layers

Initial measurement length: 150mm

Specimen diameter: 54mm

Date: 15.01.2020

No.	S [N/mm <sup>2</sup> ]	E [%]
0	0.00	0.00
1	0.01	0.55
2	0.00	0.00
3	0.01	2.71
4	0.01	3.07
5	0.01	5.11
6	4.16	6.81
7	9.93	9.24
8	5.39	11.73
9	5.40	14.12
10	5.62	16.53
11	5.16	18.91
12	5.56	21.28
13	6.06	23.60
14	7.56	25.85

15	9.35	28.16
16	10.06	30.50
17	10.36	30.49
18	10.36	35.19
19	11.41	37.50
20	11.73	39.86
21	11.85	42.14
22	13.62	44.37
23	15.04	46.62
24	16.34	48.85
25	17.39	51.15
26	17.32	53.45
27	17.04	54.52
28	14.05	54.61
29	13.19	54.64
30	12.84	54.65

Appendix 15 Output force-elongation-table

Material: glass fiber

Free Text: CSM 5 layers

Initial measurement length: 150mm

Specimen diameter: 50mm

Date: 15.01.2020

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.02	0.82
2	0.00	0.00
3	0.01	4.07
4	0.01	4.61
5	0.01	7.66
6	6.61	10.22
7	15.79	13.86
8	8.58	17.60
9	8.59	21.18
10	8.94	24.79
11	8.20	28.37
12	8.84	31.91
13	9.64	35.40
14	12.02	38.78
15	14.87	42.23

16	16.00	45.75
17	16.48	45.74
18	16.48	52.79
19	18.14	56.26
20	18.65	59.80
21	18.85	63.20
22	21.66	66.56
23	23.92	69.93
24	25.99	73.27
25	27.65	76.73
26	27.55	80.17
27	27.10	81.78
28	22.34	81.91
29	20.97	81.96
30	20.42	81.97