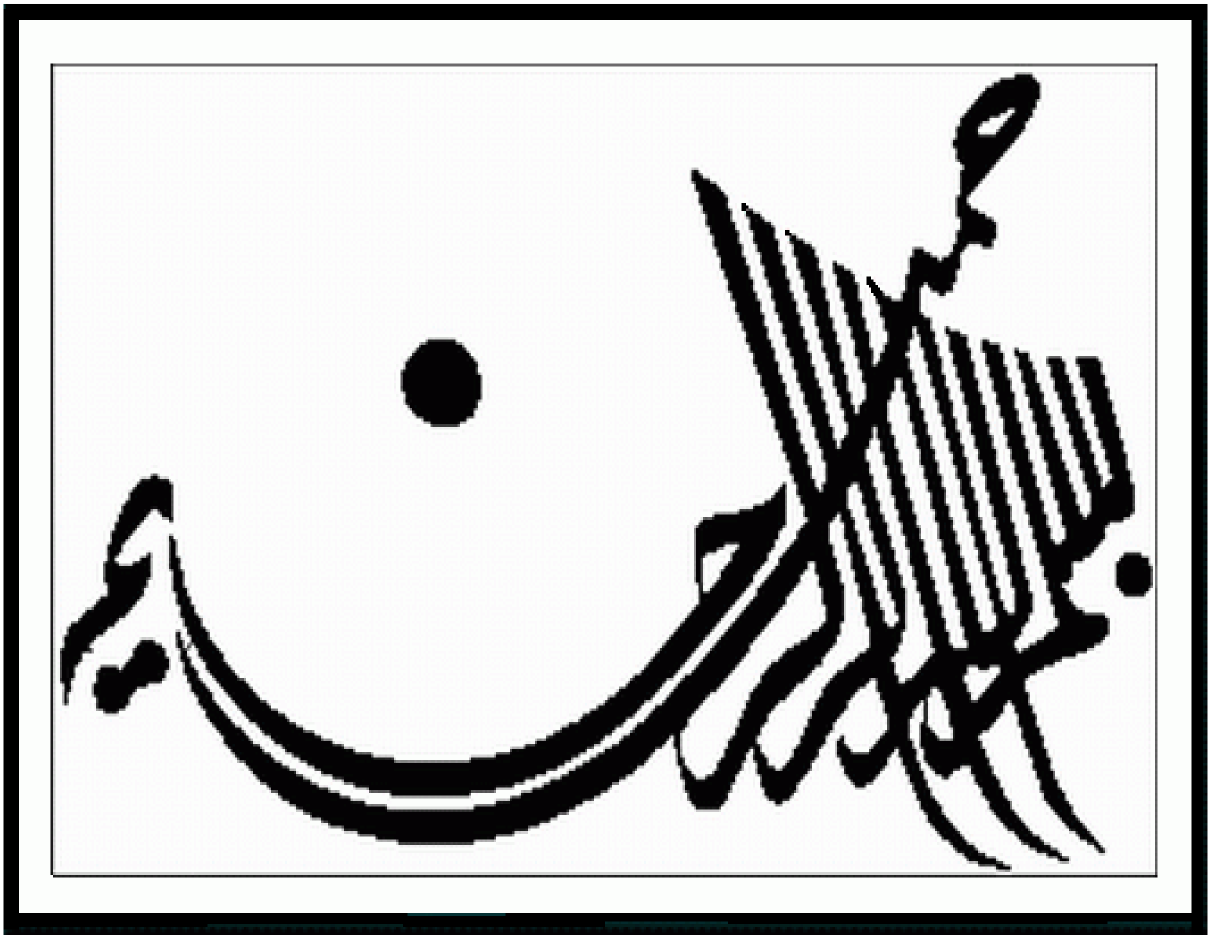
بسم الله الرحمن الرحيم

# Operating Cost Reduction of Filament Wound Glass Reinforced Epoxy Pipes by Optimization of the Oven Curing Time

Session 2016-2018

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# ACKNOWLEDGEMENTS

All praises be to the "**Allah Almighty** "the most merciful, the most beneficent who guides us in the darkness and helps us when despair surrounds us. Without His help one can't reach ones destination. Undoubtedly these are His unlimited blessings that made us complete this work. All respects and love for Prophet" **Muhammad (PBUH)** "who enlightened our minds to recognize our creator.

I thank my dear **parents**, who brought me up, fed me and above all; made me educated. Then I thank all my teachers who taught and guided me; and my dear **friend** who encouraged me and moved me for the years. To my sister who stood by me and continues to stand by me because of her staunch belief in what I am capable of.

I owe gratitude to **Bin Tariq (Pvt) Ltd.** and **colleagues** as well. They helped me coming over many ambiguities regarding our process, experimentations and research.

I express profound and cordial gratitude to my learned, kind and experienced supervisor, Dr. Muhammad Shafiq Irfan, for his kind behavior, constructive suggestions and all the way helpful supervision.

In the end, I thank all those who by any means helped me completing this project.

# ABSTRACT

There is a great demand of fiberglass pipes in Pakistan. They are manufactured by filament winding technique. There are only three manufacturers (companies) of GRE pipes in Pakistan which are unable to fulfill the complete demand of local market and the consumers go for importing the GRE pipes due to big gap in supply and demand. It is need of the hour to reduce this gap. This study helps to fill this gap by increasing the production rate on economical rates. The purpose was achieved by reducing the curing time and increasing the production rate from 15 pipes to 21 pipes per day through changing hardeners (a chemical used in the epoxy pipe manufacturing). The filament winding experiments were conducted in Sunder Production unit of Bin Tariq (Pvt.) Ltd. It is a well-known manufacturer of fiberglass pipes, fittings, FRP tanks and fiberglass boats located at Sunder Industrial Estate, Lahore. The author is working in the production department of the company.

The properties of the pipes prepared with the modified formulation were compared with the conventional pipes. Finally an economic comparison was made and it was shown that the profit margin increased by 8.3 million PKR and sales increased by 22.63 million PKR annum.

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# 1 Introduction

## 1.1 History

Composites materials become an essential part of modern way of life due to advantages such as low weight, corrosion resistance, high fatigue strength and faster assembly. Fiberglass pipe was introduced in 1948. First use for fiberglass piping still, one of the most widely used, is in the oil industry. In late 1950s, larger diameters became available and fiberglass pipe was increasingly used in the chemical process industry because of the pipe's inherent corrosion-resistant characteristic. Since the 1960s, fiberglass has been used for municipal water and sewage applications. Fiberglass pipe combines the benefits of durability, strength and corrosion resistance available in diameters ranging from 1 inch to 144 inches and pressure classes ranging from gravity applications through several thousand per square inch. Fiberglass pipe is manufactured from glass fiber reinforcement and cured by thermosetting resin. This composite structure may also contain aggregate, granular or platelet fillers, agents and pigments. The proper combination of resin, glass fibers, fillers and design create a broad range of properties and performance characteristic. Over the years, the diversity and versatility of materials used to manufacture fiberglass pipe have led to a variety fiberglass pipes as reinforced thermosetting resin pipe (RTRP), reinforced polymer mortar pipe (RPMP), fiberglass reinforced epoxy (GRE) and glass reinforced plastic (GRP). Fiberglass pipes have also been categorized by the particular manufacturing process – filament winding. The particular resin used to manufacture are epoxy, polyester or vinyl ester which grade the fiberglass pipes.

Composite materials or fiber reinforced plastic are used for manufacturing products and structures by fabrication technology is known as filament winding. This process includes winding filaments on mould or mandrel by tension force. The filament winding process is to wrap fibers in desired pattern on mandrels automatically or manually. The filament winding process is to wrap fibers in desired pattern on mandrels automatically or manually. The orientation and layering of filaments control carefully by using of computer control. The filament winding depends on winding methods and patterns. Storage tanks, pipelines, pressure vessels and cylinders, fishing rods, missile cases, rocket motor cases, ducting, cement mixture, sail boat mast, aircraft fuselages and golf club shafts of composite materials are manufactured by the method of filament winding. Carbon fiber, glass fiber and aramid fiber are most common filaments used in material technology. The cost reduction is analyzed by raw materials, process cost, utility cost, labor cost and factory cost. The reduction in operating cost is achieved by reducing the curing time through changing hardeners. The profit and sales of epoxy pipes are increased by increase of production rate per day.

## 1.2 Aim of the Study

The primary aim of this research was to develop an operating cost reduction of filament wound glass reinforced epoxy pipes by optimization of curing time oven. The specific aims of the research were as follows.

i) To optimize the curing process of glass reinforced epoxy pipe.
ii) To reduce the curing time by changing the hardener.
iii) To achieve the operating cost reduction of glass reinforced epoxy pipe.
iv) To reduce the temperature of curing oven for glass reinforced epoxy pipe.
v) To increase the production rate to reduce the supply and demand gap.
vi) To enhance the profit and increase the sale of product.

# 2 Literature Review

This chapter presents a review of the literature on topics associated with polymer composites and filament winding.

## 2.1 Polymer Composite

The term polymer refers to a molecule which composes of multiple repeating units and having high molecular weight. A composite polymer is made by two or more constituent materials along sharply different chemical and physical properties. The components combine to give product having properties different from individual components. A composite product or polymer preferred due to many logics as they are stronger, lighter in weight and less expensive when compared to conventional materials. There are many typical composite materials in engineering. Some are reinforced concrete, composite wood, reinforced plastics such as fiberglass, ceramic matrix composites, metal matrix composites and advanced composite materials.Matrix and reinforcement are two main categories of constituent materials. Matrix material is main constituent which supports the reinforcement materials by maintaining their relative position. The reinforcement relates mechanical and physical properties which increase the matrix properties. The quality and variety of matrix and materials give optimum properties. The shape of product to be formed is very concerned for engineered composite materials. Before and after the reinforcement, the matrix material is shaped into mould surface or cavity by melding phenomena such as chemical polymerization for thermosetting polymer matrix or solidification from the melted state for thermoplastic polymer composite.[1]

Molding is typical constructing process within a mold. Reinforcement is done by putting layers of fibers with resin into mold through specific ratio. The finished product manufacture according to desired design, thickness, shape and orientation and then product cure by curing heater. Molding is classified into many methods according to product design requirement. In this regard, gross quantity of material which is used in molding also an important factor. Large and small production quantities are considered with high and lower capital expenditures, tooling and laboring cost. Polymer matrix is also called as resin solution, which uses in production of composites. Polyesyter, vinyle ester, epoxy, phenolic, polyamide, polypropylene and others are different raw ingredients. The second raw ingredients are fibers also known as reinforcement materials. There are various methods which are developed to change the ratio of resin and fibers (raw ingredients). According to design, 60% fiber and 40% resin are used to form a final product and strength of product is highly dependent on this resin fiber ratio.

Fiberglass reinforced polymers (FRP) are classified into carbon fiber reinforced polymer (CFRP) and glass reinforced plastic (GRP). Ceramic is another example of composite like fiberglass reinforced polymer and cement. Asphalt and polymer concrete, mastic asphalt and syntactic foam are main composites of ceramics. There are also naturally available composites as wood. Wood is comprised of cellulose fibers in a lignin and hemi-cellulose matrix[2].Some composites have nonmetals particles such as glass, epoxy used as filler. Composites can be classified as fiber reinforced, particulate reinforced, structural composites and nanocomposites. Largely, metal matrix composite (MMC) which has metal matrix, ceramic matrix composites (CMC) which has ceramics materials and polymer matrix composites (PMC) which has organic matrix (polymer) are classification of composites. Typical fiber has silicon carbide and carbon is example of metal matrix composites. Alumina silicate reinforced by silicon carbide is example of ceramic matrix composite which demonstrates high hardness, strength, low density and high temperature limits. Continuous fiber or common organic matrix is example of polymer matrix composite which are further divided into reinforced plastics and advanced composite that demonstrates high mechanical properties such as strength and stiffness.[3]

### 2.1.1 Structure Composite

Composite materials are made by more than two components which have different mechanical properties. Composite has many types as composite reinforced by particles, composite reinforced by chopped strands, unidirectional composites, laminates, fabric reinforced plastic, honeycomb composite structure.

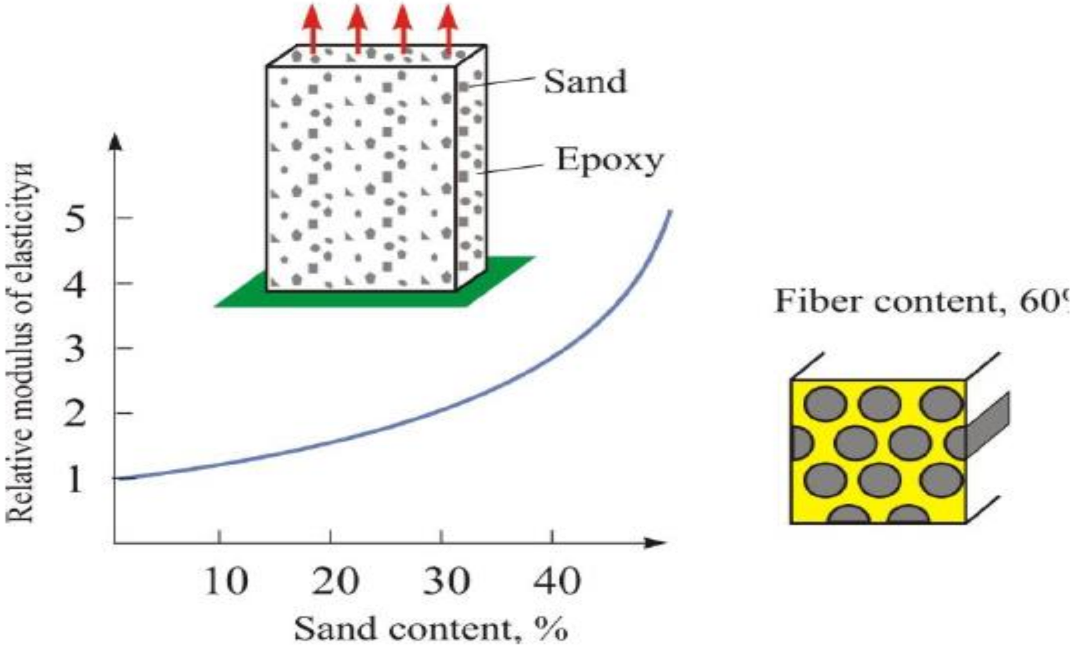

Figure 1 Sand content % verse modulus of elasticity

If we take a specimen of fiberglass pipe then by studying its cross sectional area we found that fiber content is 60% and the rest is sand. This ratio determines the modulus of elasticity. The modulus of elasticity increases as hard particle content increases.

The composites also have shear stress and are concentrated at bond surfaces between composites. In laminate composite materials, shear stress concentration is greater than in isotropic composites so the strength of material is also higher. Like the shear stress, there are also tensile stresses which cause different forces to break composite materials. Some composites like honeycomb has flexural strength and some have not. The compression load or stress depends on many parameters, like adhesive quality, size of fiber, fiber filament and many other factors.[4]

### 2.1.2 Fibers

The composite demonstrate unique mechanical properties, strength and modulus of elasticity. The critical force for a fiber is equal to the production of critical stress (strength) by the fiber area. Fiber materials are more brittle and knotted aramid fiber has more than 50% its original strength.

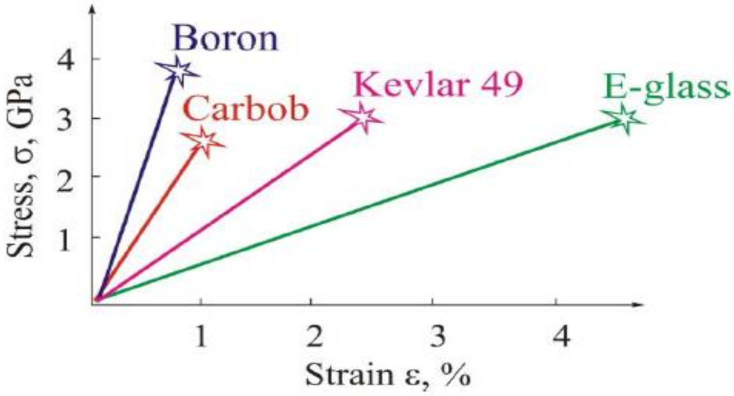

Figure 2 Stress and strain relation for different materials

There is small effect of temperature and deformation on the strength of brittle fibers such as Boron or Silicon Carbide.

### 2.1.3 Rigidity

Rigidity is measure by modulus of elasticity (Young's modulus). Modulus of elasticity has unit of stress. The modulus of elasticity of composite materials depends on many factors such as fiber content, component parameter and structure of composites. Rigidity can be in proper equation in relation with stress and strain.

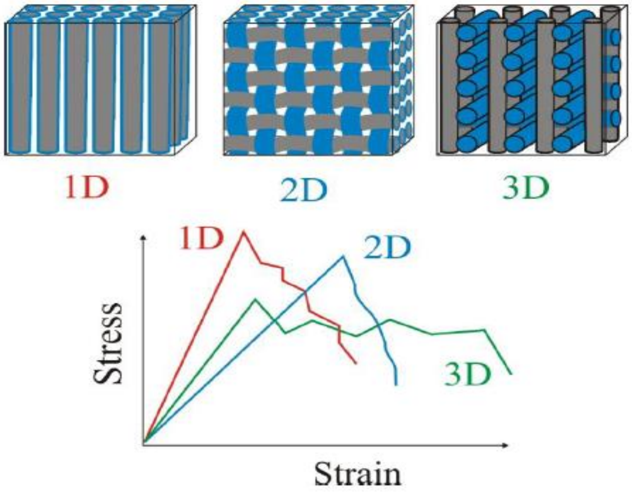

Figure 3 Stress and strain relation for 1D, 2D & 3D

Stress = Modulus of Elasticity x Strain

Boron, aramid, and carbon fibers are more rigid than aluminum or epoxy matrix. It is very concerning point that modulus of elasticity of fiber is very higher than modulus of resin. Stress is higher in more rigid component but matrix and fibers both have the same strain under load or tension.

### 2.1.4 Strength

Surface layers of composites can lose their mechanical stability under load or compression. The mechanisms how the composite fracture are entirely different under compression and tension. The initial fracture is carried by inner defects and edges. The strength of composite materials has not affected by delamination. Tensile strength of composites is more decreased by holes and cracks but less decreased by small defects.[5]

Laminate composites have greater than as compare to brittle composites. In materials engineering, a composite laminate is combination of layers of fiber materials which can be together to provide properties like in-plane stiffness, strength and coefficient of thermal expansion. The direction of applied force or load is also important as point of force or load. The cracks, voids and holes reduce the mechanical properties like strength either tensile or shear strength. Tensile strength reduces more than shear strength in the presence of holes and cracks. Impurity like water presence decreases the strength of composite. Macro cracks in the weakest fibers are surrounded by strong fibers enhance high ultimate strength. The average strength of fiber is always higher than strength of composite. The chances of fracture of composite are lower than fiber at low stress.[6]

## 2.2 Material Selection

Advanced composite materials have different mechanical properties compared to steel and metal alloys including rigidity, specific strength, fatigue strength, strength redundancy and high resistance of damaged structures to external loads. In opposite to metals, modern composite has high strength against crack resistance. Filament type, fiber content, layer orientation and other parameters give the unique properties in composite material. The composite materials are widely used in material engineering due to less weight and reduce cost effects.

Nondestructive testing is very important stage in structure materials. Ultrasonic testing is technique used in material engineering. Cracks, holes, delaminations, disbonds in adhesive, voids, porosity, inclusions and poor fillers are revealed by ultrasonic testing. An eddy currents technique is limited to materials with a conducting phase. For inspecting large scale composite structures, thermography use as rapid technique. For discovered defects as delamination and disbonding , holography technique can be used. Radiography is used in testing of boron or glass reinforced composites but not carbon reinforced composites.

### 2.2.1 Resins

Polyester, vinyl esters and epoxy resins are most commonly used in fiber or composite industries. Polyester resins have good electrical, corrosion resistance and brittleness properties change due to its chemical structure. Compatibility, service conditions and desired characteristics of finished goods are based on resin selection. Vinyl ester resins have much chemical corrosion resistance and toughness as compare to polyesters. [7]

Molding, laminating and costing operations can be performed with either system. Property retention and mechanical properties are required in composite materials and epoxy resins are widely used to achieve these properties. Epoxy resin has good chemical corrosion, electrical resistance, higher strength and better dimensional control but they are more expensive than polyester resins.[8]

#### 2.2.1.1 Polyester Resin

The most widely resin used in composite industry is polyester resin because it is less expensive, better corrosion and abrasion resistance and general purposes. Polyester resins are more resistant to temperature, easy to cure and applications. Polyester resins are widely used in storage tanks and application of fiberglass services due to their properties. There are many resins which are not compatible for applications and not well suited with all fabrics. Contrary of epoxies, fabrics like fiberglass mats have soluble binder which exhibit adhesion property better than others. Material compatibility must be check while designing and application of fabrics.

#### 2.2.1.2 Vinyl Ester Resin

Vinyl ester resins are also widely used in polymer industry and technology as polyester resin use. Vinyl ester resin is mixed form of polyester and epoxy in term of its properties, applications, uses, price and handling characteristics. Vinyl ester resin is highly compatible in chemical process industry due to its high corrosion, chemical resistance ability, temperature resistance and elongation toughness. Polyester and vinyl ester give better processing properties, reducing the friction and pulling forces, such as pultrusion at faster speed and easier separation.[9]

#### 2.2.1.3 Epoxy Resin

Epoxy resins were discovered in 1909 by Prileschajew. Epoxy resins are defined as low-molecular-weight pre-polymers containing more than one epoxide group of the form. Epoxy resins are thermosetting resins, which are cured using a wide variety of curing agents via curing reactions. Their properties depend on the specific combination of the type of epoxy resins and curing agents used. Because of their excellent mechanical properties, high adhesiveness to many substrates, and good heat and chemical resistances, currently epoxy resins are intensively used across a wide range of fields, where they act as fiber reinforced materials, general-purpose adhesives, high-performance coatings, and encapsulating materials.

Epoxy resins are formed by more than one epoxide which is low-molecular-weight pre-polymers .These resins are thermosetting, which are cured due to curing reactions by using variety of curing agents. The properties of epoxy resins are depend on the specific combination of the type of epoxy resins and curing agents used. As they have excellent mechanical properties, good heat & chemical resistances and adhesiveness are so high. Epoxy resin is widely used in polymer industry specially in manufacturing of fiberglass epoxy pipes renowned as tube well pipes. It has marvelous properties like high strength, high electrical insulation, low toxicity, low shrinkage, high adhesion to substrates, low cost and high amenability. Epoxy resins are also use in development of advanced composites and technology for many processes and application purposes. Contrary to other resins use in composites, epoxy resin is well compatible to high temperature as 175° C for reinforcement. They have fatigue strength higher than any metals and aluminum alloys. Chemical modification and advancement, increasing the molecular weight, lowering density and introduction of dispersed toughened phase in the cured polymer matrix can be enhanced properties of epoxy resins. Nano-sized organic and inorganic particles such as carbon nano-tubes, nano-clays, carbon nano-fibers and metal oxide nano-particles with epoxy resin systems can be reinforced successful. [10]

Addition of curing agent or hardener to the epoxy resin normally cures or undergoes a cross-linking reaction result no by-product or volatiles. Epoxy equivalent weight and glass transition temperature are important criteria in selecting and applying resin in composites. The curing temperature can be affected by glass transition temperature which depends on structure developed during curing process, curing temperature and curing agent. When curing temperature may changes, so it changes the glass transition temperature changes. Thermo-set and hardener formulation determine the ultimate glass transition temperature. In composite fabrication, epoxy equivalent weight is parameter like glass transition temperature which used to characterize resin application. The addition reaction of curing agent with epoxy resin is controlled by curing agent which leading to reduction in brittleness and toughness. The temperature and resin-hardener mixture determine the type of curing agent with epoxy resins. Normally, glass transition temperature and chemical resistance depend on cured temperature. Tri-bological characteristics of epoxy composites helps the epoxy resin based materials in engineering structures like in building, decks, fuel tanks, helicopter rotor blades, floor boards, airframes, automobile and aerospace due to its optimum combination of lightness, excellent specific modulus, good thermal and wear resistance.[11]

There are some new resins which are used in polymer industry. Polyurethane resins are new in the field of pultrustion. Curing agent and hardener ratio (isocyanate/polyol) affect the final properties of polyurethanes and its characteristics by changing the ratio of curing agent and hardener. Pultrustion always prefer with polyurethane because these resin systems have short gel-times. Sometime cost can be reduced and desire characteristic can be achieved by adding additives like fillers and colorants.

### 2.2.2 Roving

A loosely associated bundle of untwisted fiberglass filaments or strands is roving. Strand is a compactly associated bundle of filaments. Roving can be classified by weight and tex (gm/km) range which usually between 300 to 4800. A glass is an amorphous solid manufactured by slow cooling of liquid or fused phase quarry (crystallization at 1600°C) with minerals and oxides are formed into glass fibers. The strands or filaments of solidified glass convert into bundles of strands which wind into stable and cylindrical package.(K.L. Loewenstein, The Manufacturing Technology of Continuous Glass Fibers, 3rd revised Ed., Elsevier 1993.)

Fiber glass roving is classified as general purpose or special purpose. E-glass is general purpose fiberglass roving which is 90% used for manufacturing products by ASTM standard D 578 – 98 ‘’Specification for glass fiber strands’’. (ASTM standard D 578 – 98 ‘’Specification for glass fiber strands’’ Annual Book of ASTM Standards, ASTM.)

The rest of fiberglass roving fall into special purpose classification which has special properties. S-glass, D-glass, A-glass, ECR-glass, C-glass, M-glass are special glass roving.

P.K Gupta, Glass Fibers for Composite Materials, Fiber Reinforcements for Composite Materials, A.R. Bunsell Ed., Elsevier Publisher 1998 P-19-72

**Table 1 Classification of roving**

| **Letter Designation** | **Property or Characteristic** |
|---|---|
| E, electrical | Low electrical conductivity |
| S, strength | High strength |
| C, chemical | High chemical durability |
| M, modulus | High stiffness |
| A, alkali | High alkali or soda lime glass |
| D, dielectric | Low dielectric constant |

## 2.3 Curing Agent

Epoxy curing agents promote or control the epoxy resin curing reaction. Epoxy resin curing is accomplished by adding a curing agent. Irreversible changes in the epoxy resin occur during the curing process. The cure kinetics of epoxy resins is dependent on the molecular structure of the curing agents. Curing agents can be divided into amine-type curing agents, alkali curing agents, anhydrides, and catalytic curing agents according to their chemical compositions. Fiberglass pipes and products are used in different industries for many applications including chemical processes, desalination, piping, geothermal, irrigation, oil fields, power plant, water distribution and transmission etc.

## 2.4 Filament Winding

Composite materials or fiber reinforced plastic are used for manufacturing products and structures by fabrication technology is known as filament winding. This process includes winding filaments on mould or mandrel by tension force. [12]

A mould can move forward and backward axially or horizontally and it rotates on a spindle around on axis. Unwind fibers pass through the resin tank and impregnate with the resin completely. The filament winding process is to wrap fibers in desired pattern on mandrels automatically or manually. Porosity content and fiber reinforcement are influenced by fiber tension which determines the properties of products. Carbon fiber, glass fiber and aramid fiber are most common filaments used in material technology.[13]

The winding fibers are impregnated (coated) with synthetic resin prior to winding in composites industry is known as wet winding. The heater use to harden the resin which pre-impregnated with fibers. The winding fibers impregnate with resin on the mandrel to the desired thickness and it cures in an oven. A liner uses to maintain a seal and prevent the leaking during operation. Automation is being used in filament winding process in material technology with the passage of period and it is relatively less costly method. The orientation and layering of filaments control carefully by using of computer control. The structural properties of final product determine by the angle of fiber orientation. Hydraulic rams uses to remove the mandrel. The profile of mandrel determines the profile of product.[14]

It is observed that helical angle pattern provides greater strength as compare to high angle hoop in the longitudinal direction. The fibers are synchronized with the mandrel rotation and controlled by winding angles and the placement of reinforcement. Speed of resin bath and rotational velocity of mandrel control the winding process. Pressure vessels, pipes, tanks, poles etc are manufactured by the method of filament winding Thickness and angle fibers of the desired product are controlled by simulation.

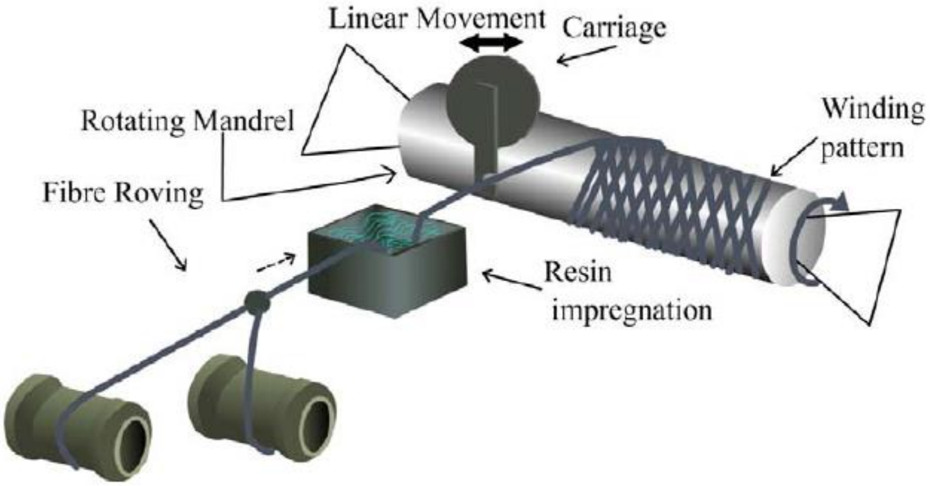

Figure 4 Filament Winding

### 2.4.1 Components of Filament Winding Machine

The filament winding machine contains the following components.

### 2.4.2 Control system

The software in automation system simulates the movement of components of machine and layering of filament over the surface of moulds. Thickness and angle fibers of the desired product are controlled by simulation. It reduces the cost of product, man power, waste of materials and time for production and makes the overall production environment cleaner and better control.

#### 2.4.2.1 Job holder

It uses of holding male mandrel on which reinforcement to be done by filament winding. Job holder should resemble one of the axes.

#### 2.4.2.2 Mandrel

There are two types of mandrel water soluble and spider/plaster mandrels. They have marvelous dimensional reproducibility and produce low cost products.

#### 2.4.2.3 Fiber creel

It holds the fiber roll or roving during the process.

#### 2.4.2.4 Carriage

It uses to handle the fibers or roving in proper orientation and placement on mandrels. A high fiber volume fraction achieve by this process. [15]

### 2.4.3 Winding Parameters

Winding methods and patterns are parameter of filament winding.

#### 2.4.3.1 Winding methods

Wet winding (post)and pre-impregnation winding processes are two types of filament winding. The resin bath uses in wet winding and fibers pass through this bath. The wet fibers wound over the surface on rotating mandrel. But pre-impregnated fibers are wound over the surface of rotating mandrel in pre-impregnation winding.

#### 2.4.3.2 Winding patterns

Hoop or circumferential is winding pattern where fiber winds at 90° angles and helical winding is winding pattern where angle lies between ranges 0° to 90°. Polar winding is the third type of winding pattern where angle of winding fibers is no long fixed and changes over the mandrel length. Winding angle can be control section by section and layer by layer. Winding angle is denoted by α. [16]

### 2.4.4 Applications

Storage tanks, pipelines, pressure vessels and cylinders, fishing rods, missile cases, rocket motor cases, ducting, cement mixture, sail boat mast, aircraft fuselages and golf club shafts of composite materials are manufactured by the method of filament winding.

Complex shaped composite products like non-cylindrical and non-spherical are engineered with the use of advancement in machinery and software.

### 2.4.5 Advantages

Filament winding produces high strength products because of control of fiber angle and it achieves high strength to weight ratio. Various sizes and shapes of composite products are engineered by this method. It enhances the production. It reduces the cost of products because of automation. Filament winding process winds the fibers in specific orientation. Winding patterns, raw materials, curing agent and curing technique can change the design flexibility of products. Filament winding includes distribution, orientation and placement of fiber uniformly.

### 2.4.6 Limitation

Filament winding demands very precise control for orientation of fiber and process. Reverse curvature (female feature) can’t be produced by this method. Capital investment is high. Within one layer of winding the direction of fibers can’t change. Two directional shapes and complex curvatures are not easy to engineer. Winding of fibers at angles is very difficult when fiber layers are parallel to axis.[14]

# 3 Materials and Experimentation

This section provides details on raw material, experimentations and tests performed in this study.

## 3.1 Materials

All the raw materials roving, epoxy resin, hardener and catalyst used in the manufacturing of GRE pipe are imported from Italy, China and Korea.

### 3.1.1 Roving

There are different types of roving available in SPU but E Glass E.W Roving 2000 TEX-A1 is used in this experimentation and manufacturing of GRE pipe. Bin Tariq imports this roving from Changzhou Pro-Tech Trade Co., Ltd.

Table 2 Technical data for Roving 2000 TEX-A1

| Item | Standard Value | Test Data | Standard No. |
|---|---|---|---|
| Nominal Tex (tex) | 1900-2100 | 1966 | ISO 1889-2009 |
| Loss on Ignition (%) | 0.50-0.70 | 0.60 | ISO 1887-2014 |
| Moisture Content (%) | 0.10 max | 0.03 | ISO 3344-1997 |
| Breaking Strength (N/tex) | 0.40 min | 0.47 | ISO 3341-2000 |

Table 3 Technical data for Roving 2400 TEX-A1

| Item | Standard Value | Test Data | Standard No. |
|---|---|---|---|
| Nominal Tex (tex) | 2220-2580 | 2369 | ISO 1889-2009 |
| Loss on Ignition (%) | 0.40-0.70 | 0.53 | ISO 1887-2014 |
| Moisture Content (%) | 0.10 max | 0.03 | ISO 3344-1997 |

| | | | |
|---|---|---|---|
| Breaking Strength (N/tex) | 0.40 min | 0.44 | ISO 3341-2000 |

Note: Testing temperature: 23°C & Relative humidity: 56%

### 3.1.2 Epoxy Resin

EPON Resin 828 is used in this study and is imported from HEXION Co. Ltd. (China). EPON Resin 828 is an undiluted clear difunctional bisphenoal A/epichlorohydrin derived liquid epoxy resin. When cross-linked or hardener with appropriate curing agents, very good mechanical, adhesive, dielectric and chemical resistance properties are obtained. Because of this versatility, EPON Resin 828 has become a standard epoxy resin used in formulation, fabrication and fusion technology. The low viscosity and curing properties of EPON Resin 828 allow its use under various applications and fabrication techniques including spraying, pultrusion, filament winding, casting, molding, pressure laminates. EPON Resin 828 can be cured or cross-linked with a variety of curing agents depending on properties desired in the finished product and the processing conditions employed.

**Table 4 Technical data for EPON Resin 828**

| **Property** | **Test Method** | **Unit** | **Value** |
|---|---|---|---|
| Epoxide equivalent weight | ASTM D1652 | g/eq | 185-192 |
| Viscosity @ 25°C | ASTM D445 | P | 110-150 |
| Color | ASTM D1652 | Gardner | 1 max |
| Pounds per gallon @ 25°C | | lbs/gal | 9.7 |
| Density @ 25°C | | g/ml | 1.16 |
| Physical form | | | Clear liquid |
| Vapor pressure @ 77°C | | mm Hg | 0.03 |

| | | | |
|---|---|---|---|
| Refractive Index @ 25°C | | | 1.573 |
| Specific heat | | BTU/lbF | 0.5 |

High performance, high strength materials are obtained when this resin is cured with a variety of curing agents. One of the most widely recognized properties of cured EPON Resin 828 is strong adhesion to a broad range of substrates. Compared to other polymers, epoxy resins have low internal stresses resulting in strong and durable finished products.

EPON Resin 828 cured system have very good electrical insulating characteristics and dielectric properties. Electrical encapsulations, laminates and molding compounds are frequently based on EPON Resin 828. It is highly chemically resistant including caustic acids, fuels and solvent. Chemically resistant reinforced structures and linings or coatings over metal can be formulated with EPON Resin 828.

The primary components of a thermosetting resin formula are the epoxy resin and the hardener or curing agent. However, in practice other materials are normally incorporated to achieve special properties. Inert fillers like silica can be added to further reduce shrinkage and improve dimensional stability. Also, reactive diluents can be added to EPON Resin 828 to reduce viscosity.

### 3.1.3 Hardener

It is essential to mix resin with its curing agent to achieve desired properties and better curing. This experimentation study has been done for reducing the curing time of GRE pipes and it is mainly done by replacing the old hardener MTHPA with new hardener KFH-9585.

#### 3.1.3.1 Old Hardener (MTHPA)

Methyltetrahydrophthalic Anhydride (MTHPA) is used in this study and is imported from LONZA SPA, Scanzorosciate (BG), Italy.

MTHPA is mainly used as a curing agent for epoxy resins. Its synonyms is 1,3-isobenzofurandione, tetrahydromethyl; 1,23,6-tetrahydromethlphthalic anhydride and chemical formula is $C_9H_{10}O_3$. It has a low tendency to absorb moisture from the air and zero or minimal formation of carbon dioxide when mixed with tertiary amine accelerators.

It can be easily blended with various liquid resins providing stable, low viscous mixture and long pot lives. It is widely used for casting, impregnation and lamination. In the field of reinforced plastics it is used for filament wound products, laminated sheets, printed circuit boards and switch gears. It can be used in productions of electrical parts such as capacitors, resistors, wiring parts etc. It must be stored away from open flames or other potential ignition source and should be protected from moisture. In winter season MTHPA can solidify, it can easily be re-melted by simply heating.

Table 5 Technical data for MTHPA hardener

| **Properties** | **Test Method** | **Unit** | **Value** |
|---|---|---|---|
| Physical State | ASTM D1652 | | Clear Liquid |
| Viscosity @ 25°C | ASTM D1652 | cps | 58 |
| Color | ASTM D445 | | 80 max Hazen |
| Acid Content | | % | 0.5 max |
| Specific Gravity @ 25°C | | | 1.197 |
| Refractive Index @ 25°C | | °C | 1.495 |

|  |  |  |  |
|---|---|---|---|
| Purity |  | % | 99.0 % min |
| Vapor Pressure @ 120°C |  | mPa.s | 2.0 |
| Shelf Life |  | months | 12 |

#### 3.1.3.2 Hardener KFH-9585 (New):

Hardener KFH- 9585 is used to improve the curing time for system and it is imported from LONZA SPA, Scanzorosciate (BG) Italy.

In this study EPON Resin 828 and KFH-9585 system is used for filament winding. This systemcontains liquid type low viscosity epoxy resin and high viscosity, less toxicity hardener with accelerator. Especially it has excellent mechanical properties, reasonable pot life and thermal properties.

Table 6 Technical data for KFH-9585 hardener

| **Properties** | **Test Method** | **Unit** | **Value** |
|---|---|---|---|
| Anhydride equivalent weight | ASTM D1652 | g/eq | 162-172 |
| Viscosity @ 25°C | ASTM D1652 | cps | 100-200 |
| Color | ASTM D445 | Gardner | Less than 1 |
| Specific Gravity @ 20°C |  |  | 1.195-1.205 |

##### 3.1.3.2.1 Mixing Ratio

The old system of resin with hardener was in ratio 100:80. Now new hardener is used with same resin in the following ratio as per trader recommendations.

| **Components** | **Parts by Weight** |
|---|---|
| Resin 828 : KFH-9585 | 100 : 88 |

#### 3.1.3.2.2 Specification for system

This specification has been given by trader - LONZA SPA, Scanzorosciate (BG), Italy.

| **Item** | **Resin 828 / KFH-9585** |
|---|---|
| Mixed Viscosity @ 25°C | 800-1200 cps |
| Cured Temp | 115 C° |

### 3.1.4 Comparison of hardeners

The comparison has been made between old hardener and new hardener.

**Table 7 comparison between MTHPA and KFH-9585**

| **Old Hardener MTHPA** | **New Hardener KFH-9585** |
|---|---|
| Low viscosity (58 cps) | High viscosity (11500-13500 cps) |
| Long port life (1-2 days) | Short port life (less than a day) |
| Curing time high (120 – 150 min) | Curing time less (30 min) |
| Comparatively high cost (490 Rs./Kg) | Comparatively low cost (470 Rs./Kg) |
| High wastage | Less wastage |

### 3.1.5 Catalyst or Accelerator

In this experimentation Ancamine ® K-54 is used as a catalyst or accelerator and it is imported from PRODUCTS AIR Ltd China.

#### 3.1.5.1 Ancamine K-54

Ancamine K-54 (tris-2,4,6-dimethylaminomethylphenol) is an efficient activator for epoxy resins cured with a wide variety of hardener types including polysulphides, polymercaptans, aliphatic and cycloaliphatic amines, polyamides and amidoamines, dicyandiamide, anhydrides. Applications for Ancamine K-54 as a homopolymerisation catalyst for epoxy resin include adhesives, electrical casting and impregnation and high performance composites. At-least 24 months from date of manufacture in original sealed container stored undercover at ambient temperature away from excessive heat and humidity.

Table 8 Technical data for Catalyst K-54

| **Properties** | **Test Method** | **Unit** | **Value** |
|---|---|---|---|
| Physical State | ASTM D1652 | | Amber Liquid |
| Viscosity @ 25°C | ASTM D1652 | P | 2 |
| Color | ASTM D445 | Gardner | 6 max |
| Amine Value | | mg KOH/g | 630 |
| Specific Gravity @ 25°C | | | 0.98 |
| Flash Point | | °C | 140 |

|  |  |  |  |
|---|---|---|---|
| Boiling Point |  | °C | 250 |
| Free Water |  | % | 0.5 max |

## 3.2 Glass Reinforced Epoxy (GRE) Pipe Process

The raw materials (roving, resin, hardener and accelerator) are imported from China, Korea and Italy. The different tests are performed on raw materials to check the quality according to the trader provided technical sheets. Specific gravity, viscosity and gel time tests are performed on resin, hardener and accelerator before production. If the results of test are not matched with the provided technical sheets then the raw materials are not being used.

The roving, resin, hardener and accelerator are used in specific ratio to achieve the optimum quality of finished product. The pipes are manufactured by the reaction of roving and resin hardener mixture in ratio 70:30. The resin hardener mixture is used in ratio 100:80 for impregnation. The curing agent K-54 is also used as a catalyst or accelerator in resin hardener mixture to improve and speed up the curing process i.e. 1% of the resin quantity. Now the hardener KFH-9585 is being used instead of old hardener in ratio 100:88 with resin.

The production unit contains automatic control machine, impregnated bath, fiber creels, curing oven, mandrels, mantling and dismantling systems. The resin and hardener is being mixed in the impregnated bath with catalyst manually. The system is feed up by automatic control after mantling the mandrels on machine. Three (03) mandrels are put on machine for same size of diameter and thickness of pipes as the machine is designed for three (03) pipes simultaneously. The roving are feed from fiber creels and passed through impregnated bath of resin hardener mixture. The roving is impregnated with resin hardener mixture and filament wound on mandrels according to the automation data. The filament winding process is done by the axial filament winding and helical filament winding which increases the strength and quality of pipe. The winding process automatically ended after achieving the required thickness of the pipes. The mandrels are moved from machine to curing oven for curing process. Curing oven has capacity to cure the three pipes simultaneously at maximum temperature 180°C. The curing oven consumes electric energy 31.7 KW/hr for heating. The curing oven works on electric heater phenomena and two blowers are used to uniform the temperature of oven. The pipes were cured after heating of about 120 to 150 minutes and pipes are cured in 30 minutes in new system. The pipes are brought out from oven and kept at room temperature. After that the pipes are dismantled from mandrels and moved for furnishing. The required blank pipes are sent to slotting machine for slotting and called strainer pipes. The pipes are checked first visually and then different tests may be performed on random pipes for checking the quality. The rejected pipes by quality department are sent to production department and accepted pipes are sent for dispatch.

## 3.3 Laboratory Tests on Raw Materials

Different tests have been performed in SPU laboratory before the use of raw materials in experimentation.

### 3.3.1 Viscosity

The viscometer NDJ-79 was attached with an adjustable clamp to a ring stand and properly leveled. Beaker was washed with brush cleaner. Dried the beaker then took the specific sample 600 ml. Electric heater attached with equipment which was used to maintain the temperature

($25^0$C). Temperature variation was controlled by electric heater. The resin sample was poured in viscometer's beaker. That beaker was placed in viscometer. The viscometer spindle was immersed into sample and switched ON the viscometer then data was taken.

Viscometer showed NDJ value, multiplied it with constant (checked by table and took constant). Removed the sample and cleaned the beaker very carefully.

### 3.3.2 Specific Gravity

Two bottles (25 ml) was washed with brush cleaner for specific gravity. Dried and cleaned the bottles and then weighted them separately. One bottle was filled with water and other with resin. Both bottles weighted again after 2-3 minutes.

The specific gravity of resin can be calculated by

Specific gravity = (Wr-Wrb/Ww-Wwb)*10

Wr=weight of bottles with resin

Wrb=weight of bottles without resin

Ww=weight of bottles with water

Wwb=weight bottles without water.

Figure 5 Instrument for determine specific gravity

### 3.3.3 Gel Time

The epoxy resin (material), hardener and accelerator were proportionally mixed in a stainless steel container and stirred by wood or steel stirrer. Added the amount of accelerator in resin as designed by manufacturer and stirred till it absolutely dispersed. Then it immersed in a water-bath and made sure that bubbles dispersed during the stirring. The stirrer started to stir the mixture when the catalyst added in mixture and recorded the time. The stirrer stopped till the mixture completely gelled and the recorded time accounts into gel time (min). The experiment is carried out at 25°C.

## 3.4 Experiments

Series of experiments were performed at production unit of Bin Tariq Private Limited located Sunder Industrial Estate Lahore. Epoxy resin 828 and hardener MTHPA with curing agent K 54 were used for manufacturing of fiberglass epoxy pipes by filament winding process in production unit. The ratio of epoxy resin with hardener was 100: 80 with 0.5% to 5% curing agent. The electric oven was used for curing purposes and pipes were cured fully at temperature up to 180°C for 120-150 minutes. The curing process requires sufficient time and heat (electric current) to cure which also reduces the production rate and effects product cost.  So, optimization of production cost and modification in curing process is need of hour.

In laboratory and production unit, we have done experiments by using new hardener KFH-9585. 100 parts of epoxy resin with 88 parts (100:88 ratio is given by manufacturer, KUKDO Chemical Co. Ltd) of new hardener KHF-9585 were taken at different conditions and experiments were performed.

### 3.4.1 In laboratory - Bin Tariq, Sunder Estate Lahore

50 grams of epoxy resin was taken in a specific pot. Then added 44 grams of hardener KHF-9585 and mixed gently. We didn't add the curing agent Ancamine K54 in a mixture which was to be added in 1% of epoxy resin. The mixture was placed in laboratory oven at 100°C for 30 minutes. We observed that mixture was not cured and there was no change even in a state. It was placed in laboratory shelf (room temperature) for few minutes and observed that mixture started gelling gradually and eventually become hard. The color was brownish. The following is a reference picture.

50 grams of epoxy resin, 44 grams of hardener and roving pieces were taken in pot without any

**Figure 6 Picture of Mixture Cured at 100°C for 30 minutes**

agent K54. The mixture was heated in oven at 100°C for 30 minutes. The same behavior has been observed as above but it did not harden after switched off the oven and it remained in state of jelly. The color was greenish/yellowish.

**Figure 7 Picture of Resin Mixture with Roving Pieces**

After performing the above experiment it was decided to add curing agent K54 in a mixture. We put the mixture of 50 grams, 44 grams and 2.5 grams (5%) of epoxy resin, hardener and curing agent K54 respectively in laboratory oven at 100 C for 30 minutes. When it took out of the oven it seemed like jelly and later it was cured. The color was yellowish brown.

**Figure 8 Picture of resin mixture with curing agent**

Again 50 grams of epoxy resin was taken in a specific pot. Then added 44 grams of hardener KHF-9585 and 2.5 grams curing agent K54 then mixed gently. This mixture was impregnated with roving on small mandrel and kept the sample in laboratory oven at 100°C for 30 minutes.

The sample was seemed to be cured satisfactory after took out of the oven. So, it was decided to manufacture a small length piece of epoxy pipe to check the actual conditions of fabrication.

**Figure 9 Picture of Laboratory Experimentation of Roving with Hardener**

### 3.4.2 In Production Unit – Bin Tariq, Sunder Estate Lahore

A sample of 150mm (6 inches) diameter epoxy pipe was manufactured by filament winding process in production unit. A roving has been wounded on mandrel by impregnation of 2500 grams epoxy resin, 2200 grams hardener and curing agent 125 grams (5%) through resin bath. It was cured at 100°C for 30 minutes duration in curing oven installed at factory. It was observed that sample was not cured properly. Pot life of mixture was also observed and it was about 25 minutes.

**Figure 10 Picture of Manufactured Pipe at Production Unit**

Again manufactured same diameter sample with same ratios of raw material (2500 grams epoxy resin, 2200 grams hardener and curing agent 125 grams) by same method mentioned above. The sample was cured at 140°C temperature for 30 minutes in curing oven. The prepared sample was cured fully and its pot life was about 25 minutes.

Figure 11 Picture of Cured Pipe at 140°Cat Production Unit

Once again we manufactured sample of 150mm (6 inches) diameter epoxy pipe by filament winding process with same ratios of raw material in production unit. It was cured at 130°C for 30 minutes in curing oven installed at factory. The sample was fully cured and its pot life was same. So, we decided to set pot life in laboratory by experimentation.

Figure 12 Picture of Cured Pipe at 130°C at Production Unit

### 3.4.3 In laboratory - Bin Tariq, Sunder Estate Lahore

50 grams of epoxy resin and 44 grams of hardener KHF-9585 was place in a specific pot without roving. Mixture was mixed gently. Curing agent Ancamine K54 only 0.25 grams (reduced from 5% to 0.5%) was added and placed it at room temperature over a night. It was gelled over the night.

Figure 13 Mixture Gelled Over Night at Laboratory

A mixture of 50 grams of epoxy resin, 44 grams of hardener KHF-9585 and 0.25 grams curing agent K54 (reduced from 5% to 0.5%) was mixed gently. The mixture was impregnated with roving on pipe and kept the sample in laboratory oven at 100°C for 30 minutes but it was not cured fully. Another sample was prepared and was heated at 125° C for 30 minutes which was found fully cured. The port life was being observed.

Figure 14 Sample Prepared at Laboratory with 0.5% K54

Further, one more sample was prepared with 50 grams of epoxy resin and 44 grams of hardener KHF-9585. The curing agent K54 reduced from 0.25 grams to 0.20 grams (0.5% to 0.4%). The mixture was impregnated with roving on mandrel and kept the sample in laboratory oven at 125 °C for 30 minutes. The sample was cured fully and port life was again under observation.

Figure 15 Sample Prepared at Laboratory with 0.4% K54

### 3.4.4 In Production Unit – Bin Tariq, Sunder Estate Lahore

Now it was decided to manufacture sample by filament winding machine without usage of curing agent K54. A sample of 150mm (6 inches) diameter epoxy pipe has been manufactured by filament winding process in production unit. Roving was wounded on mandrel by impregnation of 2500 grams epoxy resin, 2200 grams hardener through resin bath without curing agent. It was cured at 150°C for 30 minutes in curing oven installed at factory. It was observed that sample was fully cured and its pot life was 7-8 hours. The following sample picture is for reference.

**Figure 16 GRE Sample Prepared through Filament Winding without K54.**

## 3.5 Laboratory Tests on Samples

The different tests have been performed on products at SPU to check the quality of pipes according to ASTM standards. To check the quality of manufactured samples following test were performed.

### 3.5.1 Loss of Ignition

50 grams of sample by weight was taken. The sample was dry and non-fractured. The test performed at 28°C temperature and 55% relative humidity. Heated or ignited the sample at 500 to 600°C for 4 hours in desiccators at a uniform and moderate rate until only ash and carbon remained. Cooled the residue to room temperature and weighted. (ASTM D-2584)

W1= Sample Weight (before heating)

Time of Heating= 4hrs

Temperature =500+$^{0}$C

W2 = Sample Weight (after heating)

**Ignition Loss Weight %= [(W1-W2)/W1]*100**

The loss of ignition result gives the value of glass quantity and rest shows the resin value which is burnt.

### 3.5.2 Barcol Hardness

The instrument (barcol compressor) was placed on sample and tested the sample on flat and hard surface. The point sleeve of the instrument was set on sample. The legs of barcol compressor were placed on the same surface. Instrument was grasped firmly. Sufficient pressure was applied downward quickly and recorded the highest reading.

### 3.5.3 Universal Testing Machine

Universal testing machine (UTM) is used to perform strength tests of different materials. UTM is also known as universal tester or material testing machine and later it was called as tenso-meter. It is used to perform many standard tensile and compression tests on different materials and structures. Tensile strength and compressive strength test of epoxy pipes were done on manufactured samples in production unit. Test specimen was grasped between the fixed member and movable member of the testing machine. The sample was inserted and clamped so that the long axis of the test specimen coincided with the direction of pull through the centre line of the grip assembly. The load applied on the sample which drove movable member in a uniform, controlled velocity with respect to the stationary member. The load was showed by the meter on machine and it showed the deflection also. (ASTM D638)

# 4 Cost Reduction

The purpose of this research is to increase the production rate of epoxy pipes which is achieved by reducing the curing time with the help of new hardener KFH-9585. Conventionally pipes were manufactured by old hardener MTHPA and sample pipes for this study were manufactured by new hardener KFH-9585. The economical analysis has been done on both systems with respect to raw materials, labor cost, curing time and curing temperature.

## 4.1 Raw Materials Cost

At first comparison was made with respect to raw materials of pipes. The raw materials of epoxy pipe were same in both cases except the hardener and catalyst. Old hardener was MTHPA and new hardener is KFH-9585 used in experimentation and research work. The cost of pipe is changed due to low price of new hardener and less or no usage of catalyst K-54. The pipes are manufactured by using roving, epoxy, hardener and catalyst. Cost calculation is done on pipes having diameter 6 inches, thickness 5 mm and length 20 feet on both systems. The cost for new pipe is 123.35 PKR per pipe less as compared to conventional pipes.

## 4.2 Curing Process Cost

Impact of reduction in curing time of pipes on cost is analyzed. The power required for curing oven is 31.7 KW/hr and price of one unit (KW/hr) is 16 PKR. Curing oven in Sunder Production Unit (SPU) has capacity to cure three (03) pipes simultaneously. It is important to remind that 15 pipes were manufactured by conventional method with the help of old hardener. The pipes were cured in 120 minutes during the conventional method. The cost of curing process of one pipe was 338.10 PKR (conventional method). The research was made on new system by replacing the hardener KFH-9585 with old hardener MTHPA which increased the production rate by reducing the curing time and curing temperature. The curing process time has been reduced from 120 minutes to 30 minutes and pipes were cured at 130 °C instead of 180 °C. The cost of curing process of one pipe is 84.5 PKR (new method) which made remarkable reduction in cost i.e. PKR 253.60

## 4.3 Labor Cost

Although the manufacturing process is automatically control but it requires specific labor for managing raw materials, mantling & dismantling the pipes and supervision of production and process. The labor cost has been managed in cost of pipe i.e. 10% of the raw material cost. The cost of raw material for one pipe is 8222.35 PKR and the labor cost of one pipe in conventional method was 822.23 PKR. After modification of system by changing the hardener, the numbers of pipes has been increased from 15 to 21 which reduced the labor cost per pipe i.e. 234.925 PKR because the number of workers in unit remained constant.

## 4.4 Factory Cost

The sale price of pipe contains the cost of raw material, utility cost, labor cost, factory cost and profit. The production unit has different expenses which are accumulated in cost of pipes by adding again 10% of the raw material cost. This category is comprised of all the costs which are must needed to run a factory i.e. equipment depreciation, equipment maintenance, factory rent, factory utilities, wastage in raw material handling and supervisor salaries. The production rate has been accelerated which also increased the factory cost per pipe i.e. 234.925 PKR because all the remaining factors in unit are remained constant.

## 4.5 Cumulative Cost Reduction

The cost reduction has been analyzed by raw materials, utility cost, labor cost and factory cost.

Table 9 Cumulative cost reduction

| **Description** | **Cost with Old Hardener ( PKR)** | **Cost with New Hardener ( PKR)** | **Reduction in Cost ( PKR)** |
|---|---|---|---|
| Raw Materials Cost | 8222.35 | 8099 | 123.35 |
| Curing Process Cost | 338.10 | 84.50 | 253.60 |
| Labor Cost | 822.235 | 587.31 | 234.925 |
| Factory Cost | 822.235 | 587.31 | 234.925 |
| **Total Cost Reduction per Pipe** | | | 906.2 |

The following graph shows the clear reduction in cost.

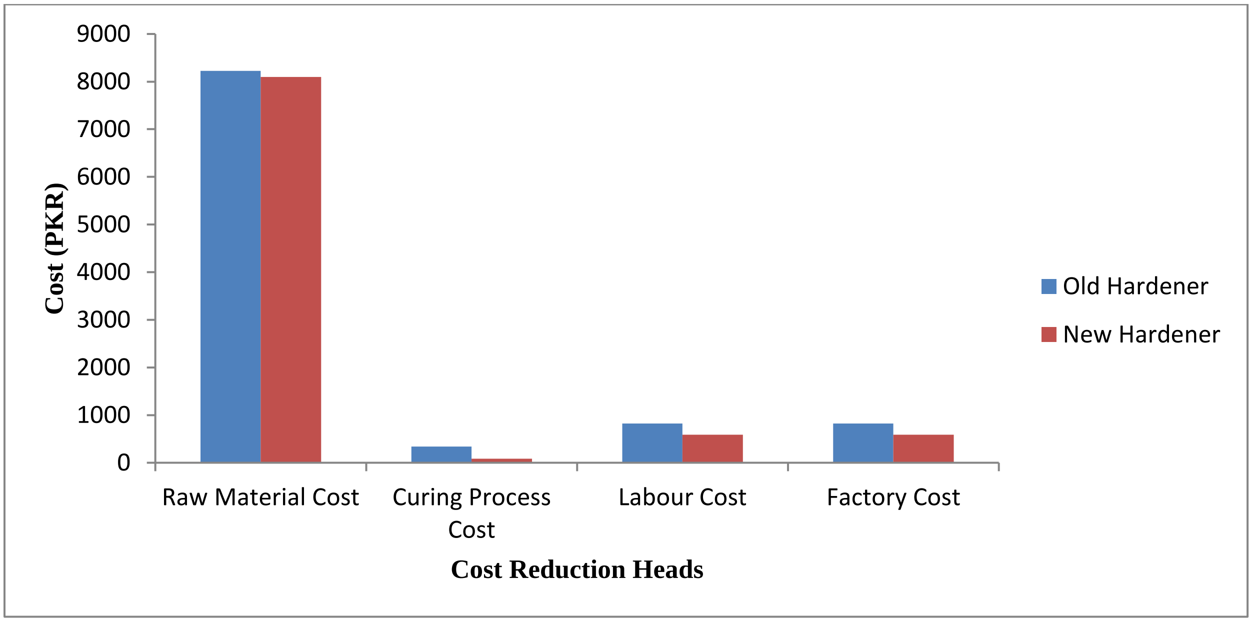

Figure 17 Graph for Reduction in cost

# 5 Results and Discussion

This section presents the results of laboratory tests and experimentations performed at SPU which are associated with this study. Discussion will be done to correlate the results and objective of the study.

The GRE samples manufactured for this study with variation of catalyst K54 from 5% to 0% in production unit SPU. It has been observed through laboratory tests (Chapter # 3) the quality of GRE pipes is not affected by eliminating catalyst from the resin mixture. It is determined the pipes were fully cured and this absence of catalyst doesn’t affect the curing process. Moreover it was analyzed the port life of the mixture with new hardener is comparatively low i.e. 7-8 hours. It is important to note, this port life of KFH-9585 hardener mixture doesn’t has any impact on quality of pipe and process (Fig 17, 18 & 19).

The production is increased from 15 pipes to 21 pipes per shift (8 hours) i.e. productivity is increased 28% which has been established in experimentation (Chapter # 3) by replacing of hardener MTHPA with hardener KFH-9585 in order of curing time reduction. Moreover, the cost of product is reduced by replacing the hardener i.e. 906 Rs per pipe which is 7% of the sale price (Chapter # 4). Product quality of new system has been analyzed after achieving the cost reduction by reducing curing time.

As discussed in chapter # 3, the raw materials are imported from China, Korea and Italy. Traders provided the technical data which is also mentioned in same chapter. Viscosity, specific gravity and gel time tests have been performed on raw materials in SPU laboratory before converting the raw material into useful product by winding process and data was collected. The tests data were matched with technical data sheet.

The GRE pipes were manufactured with resin EPON 828 and hardener KFH-9585. Different types of test have been performed in SPU laboratory and data has been collected. The comparison is made with old hardener pipes by the graphs to analyze the quality of pipes. Firstly, loss of ignition (LOI) test is performed on new hardener pipes and compared with old system pipes.

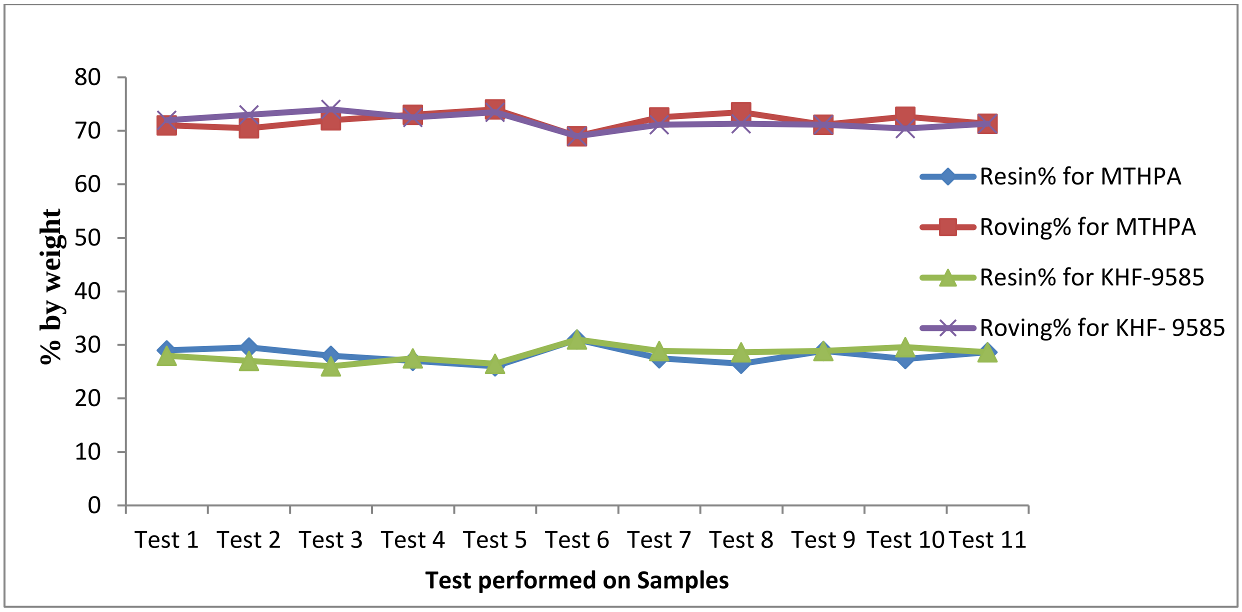

**Figure 18 Comparison Graph between MTHPA & KFH-9585 Hardeners for Loss of Ignition (LOI)**

Loss of ignition (LOI) is performed to check the ratio of glass and resin hardener mixture. The ratio is one of the main factors to determine the quality of pipe according to manufacturing ASTM standard D 2584. The loss of ignition tests indicated that the ratio of glass and resin hardener mixture was same as per ASTM which showed the quality of pipes.

Barcol hardness tests have been performed on same pipes which are manufactured with hardener KFH-9585 and data was collected. The test shows the hardness of the surface of pipe which should between the range 60-70 as per ASTM D2583 / BS 4549. This showed the quality of curing during the process. Comparison of barcol hardness value is made between both systems pipe. Following graph indicated that the hardness of GRE pipes is according to ASTM which showed the quality of pipe.

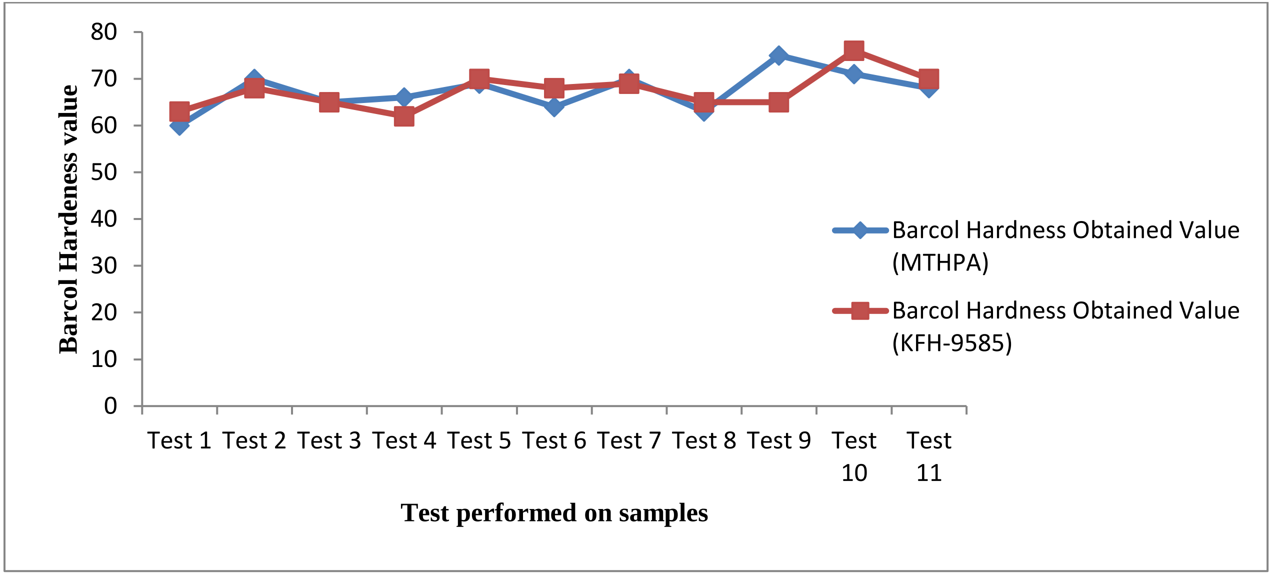

**Figure 19 Comparison graph between MTHPA & KFH-9585 hardeners for Barcol hardness**

After the loss of ignition and barcol hardness test, now tensile tests have been performed on same pipes which were manufactured with hardener KFH-9585. The tests showed the strength of pipe which should between the range 41,000 kgf to 45,000 kgf as per ASTM standard D 638-03. The tensile strength determines the quality of raw materials and curing process. The comparison between two systems is made with respect to axial tension load pipe value. The following graph indicated that the strength of GRE pipes is according to ASTM

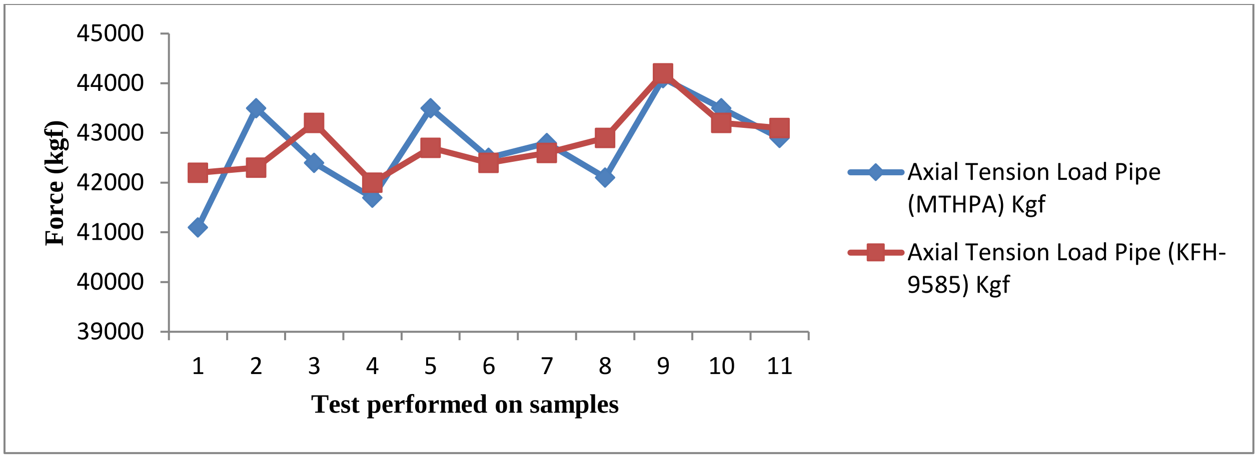

Figure 20  Comparison between MTHPA & KFH-9585 Hardeners for Tensile Strength

The objective of the study has been achieved by reducing the curing time of pipes and curing temperature due to the addition of hardener KFH-9585 instead of hardener MTHPA. The experimentation showed that the advancement in curing process resulted in the reduction of curing time from 120-150 minutes to 30 minutes and curing temperature from 180 C to 130 C which optimized the process and cost successfully. The graphs are made against the curing time (min) of MTHPA verse KFH-9585 and curing temperature (C) of MTHPA verse KFH-9585.

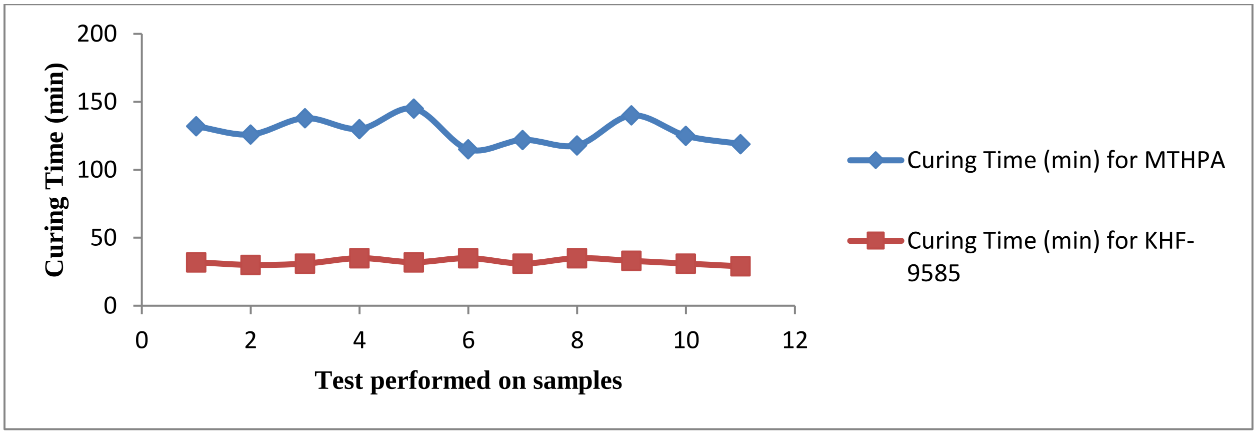

Figure 21 Comparison graph between MTHPA & KFH-9585 hardeners for curing time (min)

The result showed the clear difference between the old and new hardener systems. The large reduction in curing time saved the utility consumption and increased the productivity.

It is important to highlight that the new hardener system cured at less temperature than old hardener system. The energy in term of heat or temperature cures the pipes and this energy is also being saved by reduction of curing temperature from 180 ˚C to 130 ˚C. The following graphs clearly showed the results of difference between old and new hardener systems.

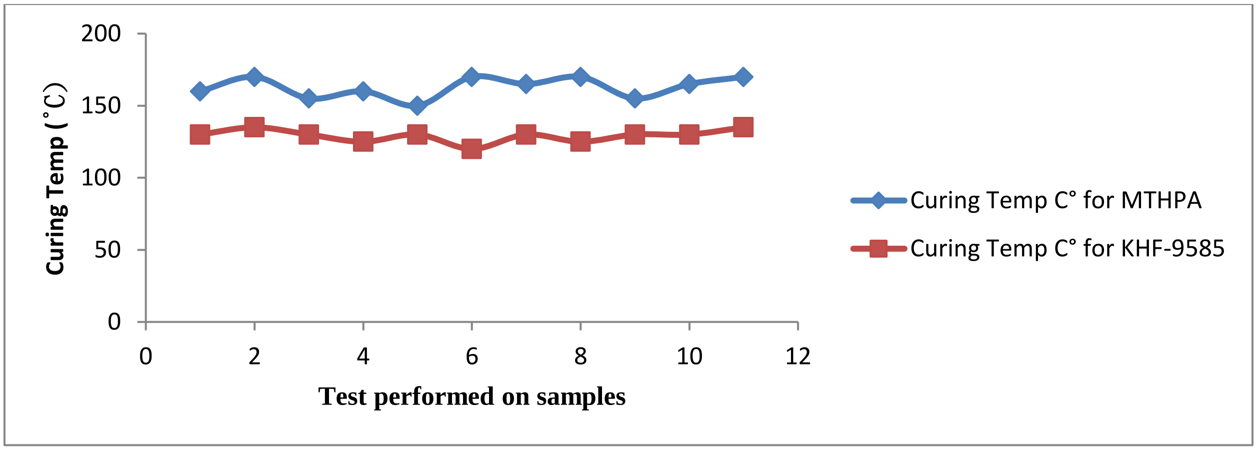

Figure 22 Comparison graph between MTHPA & KFH-9585 hardeners for curing temp (C)

The profit margin, cost optimization and sales of pipes increased by reducing the curing time. The reduction cost accumulated in profit margin which increased the net profit from 2795 Rs to 3700 Rs per pipe i.e. 21.5% to 28.5%. Further the reduction in curing time perpetuated the production rate (15 pipes to 21 pipes per shift) which enhanced the sales or profit. 15 pipes gave the profit 41,925 Rs (2,795 Rs per pipe) and 6 pipes gave the profit 28,668 Rs (4,778 Rs per pipe) so the accumulative profit per day is Rs 70,593 instead of Rs 41,925 (59.3% profit per day increased due to all factors). The profit will increase from 12.16 million rupees to 20.47 million rupees per annum i.e. 8.3 million rupees per annum (290 working days per annual). The sales of epoxy pipe will increase from 56.55 million rupees to 79.17 million rupees per annum i.e. 22.62 million rupees per annum (290 working days per annual).

So the research proved the objective of study by cost optimization of filament wound pipes through reducing curing time with the help of replacing hardener.

# 6 Conclusion & Recommendations for Future Research

The primary aim of the research reported in this thesis was cost reduction and optimization of curing time of filament wound reinforced epoxy pipe and its effect on quality. The objective of study achieve by reducing the curing time and increasing the production rate per day through changing hardeners. The modification in curing process also improves the quality of filament wound fiberglass reinforced epoxy pipes. The research also demonstrated the sufficient increase in profit and sales.

The following conclusions are drawn from the research.

*Curing Process*: The production rate directly depends upon the filament winding and curing process. The curing duration depend upon the temperature and resin mixture, thus the curing process has been modified by replacing the anhydride hardener KFH-9585 from MTHPA hardener. Temperature of oven cannot be elevated beyond deflection temperature in this case it is 130°C because it can deteriorate mechanical properties of GRE pipe.

*Curing Time*: After the cost of raw material, the curing process accumulates the large cost in production of GRE pipes. The curing oven consumes the electric power 31.7 KW/hr. The study reduced the curing time from 120 min to 30 min which reflects in cost reduction too.

*Curing Temperature*: The study achieved the objective of cost reduction by minimizing the curing time and lowering the curing temperature from 180°C to 130°C.

*Production Rate*: As the approach of study reduced the curing time, the production of GRE pipes increased from 15 pipes to 21 pipes per day.

*Catalyst K-54*: Accelerator or catalyst K-54 was used in the conventional method for better and speed up the curing process. It has been proved in experimentation that quality pipes are manufactured without usage of any catalyst.

*Cost Reduction*: The main aim of study was cost reduction of GRE pipes. Replacing of new hardener KFH-9585 depicted the process and cost in a profit term. The mainly cost reduction has been achieved by reduction of curing time which saved the electric power and increased the production rate. The study achieved the cost reduction (labour cost, factory cost, raw material cost and curing process cost) 905 PKR per pipe which is 9.7% of the cost of epoxy pipe.

*Profit*: The cost reduction increased the profit margin and sales of pipes by reducing the curing time. The reduction cost accumulated in profit margin which increased the net profit from 2795 Rs to 3700 Rs per pipe i.e. 21.5% to 28.5%. Moreover, the profit increased from 41,925 PKR to 70,593 PKR per day (59.3% profit per day increased due to all factors) by increase of production. The profit will increase from 12.16 million rupees to 20.47 million rupees per annum i.e. 8.3 million rupees per annum (290 working days per annum).

*Sales*: The sales of epoxy pipe will increase from 56.55 million rupees to 79.17 million rupees per annum i.e. 22.62 million rupees per annum (290 working days per annual) by increase of production rate and reduction in cost.

*Quality*: The physic-chemical tests established the quality and strength of pipes according to ASTM standards. The comparisons, interpretation of tests data and graphical analysis in research established the cost reduction along with improved quality.

So the research proved the objective of study by cost optimization of filament wound pipes through reducing curing time with the help of replacing hardener.

## 6.1 Recommendation for Future Research:

The study should be done on replacing of epoxy resin and investigate the effects on quality of pipes.

The research should be done to modify the impregnation and curing process for better quality and cost reduction.

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