

Failures Analysis of E- Glass Fibre reinforced pipes in Oil and Gas Industry: A Review

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Abstract: A comprehensive review is conducted on 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. The recent findings and challenges performed in conducting research regarding the deterioration caused in glass fiber reinforced pipes are highlighted and each type of failure that was identified was illustrated with an appropriate high resolution photograph. Performing creep resistance and fatigue analysis are new aspects which are still required to be analyzed which have not been stated in the literature which are nominated.

Keywords: E-Glass, composite pipes, Failures, Moisture, Air bubbles, Exothermic, Creep resistance.

1. INTRODUCTION

Fibre-reinforced polymer (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. Despite the advantages of GFRP pipes, their application is still limited mainly due to inadequate knowledge of failure mechanism and unsatisfactory methods of evaluating the deterioration. 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. It is also a challenge because it includes many variables (resins, fibers, design, manufacturing, and environment). The failures which are occurring in the pipes are in the form of short and long term considerations. 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 mould 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. They are also many other factors for failures in their performance, recent developments in computational techniques have shown the researchers to find more challenging problems. More research in this area has been done with composite materials by using different materials. As per the work done by Roham Rafiee et al, 2016 [1] and his team, constraints in the failure of composite pipes fall into two main categories of short-term and long-term requirements in accordance with international rules and regulations. For the long-term considerations, creep phenomenon, fatigue failure and environmental issues are the most important topics. Figure-1 shows the Layout of GRP Wall construction during the manufacturing process.

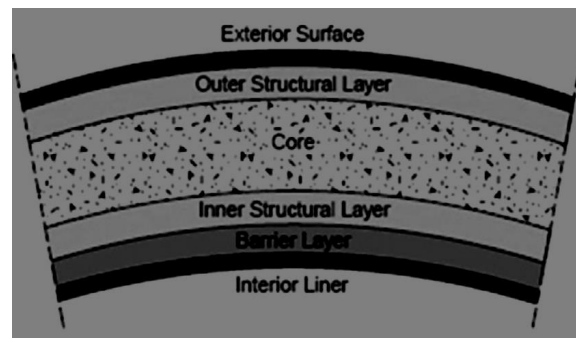


Figure-1: Systematic representation of GRP Wall construction [1]

The methods used for manufacturing GFRP Pipes sometimes may result in the failures in the long time run. The study indicates the failures and possible solution to eradicate the problems caused during the manufacturing and installation process of the pipes.



Figure-2: Systematic process of winding and applying resin during the preparation of E-Glass fiber reinforced pipe

2. LITERATURE REVIEW

Failures in GFRP Pipes have been analysed by lot of researchers from various aspects in accordance to growing demand of GFRP pipes in industrial applications. Investigations were done by Shahram Eslami a, Abbas Honarbakhsh-Raouf a, Shiva Eslami b et al. [2] and they found out that composite specimen when subjected to humid conditions underwent mechanical degradation, will cause a decrease in the failure force and maximum displacement in the buckling tests. These reductions became more considerable when the exposure temperature rose from 2°C to 25°C or the ageing environment changed from sea water to water. Yao and Ziegmann[3] have experimentally conducted tests on influence of water absorption to check the durability of GRP pipes. In an experimental Study conducted by Mertiny et al. [4,5] has observed a leakage in a filament wound tube with $\pm 60^\circ$ at both room and a elevated temperature of 100°, two different resins such as epoxy and bismaleimide were used during the experimental tests with three different loading rates and their leakage stress were recorded and compared and finally it was concluded that bismaleimide have exhibits higher leakage strength than epoxy. In the work done by other researchers buchler and Seferis [6] they found out that diffusion of water may reduce the mechanical properties of epoxy/ glass composites. Hygrothermal degradation can be worsened by absorption and desorption cycles. Arikanat et al [7] has observed crack in the specimen with different crack angle such as 0°, 15°, 30°, 45°, 60°, 75°, 90°, three failure stages of whitening with micro-crack, a pinhole leakage, and burst have been observed. Hull et al. [8] have investigated failures in filament wound GRP pipes designed with helical angle of

54.73° and inside diameter of 50 mm with the wall thickness of 1.5 mm. having both closed-end and unrestrained ends by internal pressure tests and also different modes of failure were observed by the researcher depending on the biaxial or uni axial loadings. For the closed-end situation, non-linear stress/strain response was observed due to resin cracking and seemed that fibre and resin de bonding had occurred at high pressures. For the case of biaxial loading, it was observed that weep age attributed to the transverse cracking of the resin and resin/matrix interface happened at about 20% of the burst pressure. Bakaiyan et al, 2009 [9] have analysed thermo mechanical loading of composite pipes subjected to internal pressure and a temperature gradient using 3-Dthermo-elasticity. Two ply configurations with $[\pm 55]_2$ and $[\pm 35/90]_2$ were tested. E-Glass Fiber strength reduces sometimes due to tension induced in the fibers during the process of lamination to reduce this tension Daisuke Tabuchi, Takaosajima, Toshiro Doi, Hiromichi Onikura, Osamu Ohinisi et al, 2011 [10] have developed a machine based on the fiber-reinforced plastic (FRP) manufacturing method and have observed that this machine produces 12-39% more stiffness than conventional method. Xavier Gabrion et al. [11] have observed two types of failures were observed for GFRP material at ambient Temperature, the largest proportion of tested specimens (75%) had a brush-like failure and the second type of failure was cascade-like failure. Jacquemin and Vautrin [12] studied the effect of cyclic hydrothermal degradation in thick composites pipes. They found a strong stress concentration (and therefore fatigue) within a narrow region near to the surfaces where holds the periodic moisture concentration. Davies et al. [13] have studied long term behaviour of epoxy-anhydride/glass composite tubes exposed to hydrothermal ageing. They found that after 7 years of immersion in distilled water at 60°C, the tubes showed a decrease in Tg from 124°C to 86°C. They have also found a dramatic fall in the expected lifetime if the temperature of immersion exceeds the 60°C (less than 1 year at 80°C). The lower values of Tg found in the failed tube suggests that the operation temperature could have been higher than the maximum operation temperature (65 °C). The composition of the transported fluid can worsen the operation condition by adding, to the hydrothermal degradation, the plasticizing action of the low molecular weight organic compounds [14]. Ferry et al. [15] has done an experimental device to collect time-to-failure data on filament wound pipes loaded in axial direction. The specimens with winding pattern of $[\pm 55^\circ]$ were subjected to tensile creep tests up to 500 h. Highly scattered data originated from the manufacturing process have motivated them to present the results in the form of a two-parameter log-normal or Weibull statistical distributions. Yao and Ziegmann [16] have done tests to find the equivalence between temperature and moisture in an accelerated test method using short-term creep tests on filament wound GRE mortar pipes. They have conducted short- and long-term creep tests for predicting long-term properties. Relying on this issue that both moisture and temperature have the same effect on the modulus, a moisture aging superposition principle was suggested. The proposed principle was then applied to the results of three-point bending tests to obtain long-term data from short-term properties. The effect of winding angle on fatigue strength was investigated theoretically and experimentally in GRP pipes that were exposed to close-ended internal pressure. They reported that the optimum winding angle for the composite pressure cylinders or vessels under internal fatigue pressure load was obtained as $\pm 45^\circ$ orientation [17]. Burst strength and impact behaviour of hydrothermally aged glass fibre/epoxy composite pipes were found out practically by using experimental data by A. Hawa a, M.S. Abdul Majid a, M. Afendi a, H.F.A. Marzuki b, N.A.M. Amin a, F. Mat and A.G. Gibson c [18] and also they found out that Weepage and eruption failures are occurred depending on the applied impact energies. A Samanci l, N Tarakc, iog~ lu and A Akdemir [19] have worked on pre-crack angle on quasi-static crushing behaviour of filament wound CFRP cylinder was systematically. In the case of failures caused due to moisture content F. Jones et al. [20] have developed a model which shows the diffusion characteristics of two phase

polymer material and observed that moisture absorption desisted from Fickian behaviour and approach. I.Mondargon et al. [21] have concluded that Moisture absorption kinetics depends on temperature and observed the weight variation of the specimen until the absorbed moisture has been accepted by all cases of Fick's Law. According to M.Muller et al. [22] penetration of water or moisture within glass filaments or fibers would cause disruption of adhesion which further reduces the strength of the glass fiber reinforced laminate. The work done by researchers Thomas J Barnell, Michael D. Rausher, Rick D. Stienecker, David M. Nickson, Tat H. Tong [23] have found out that during fiber reinforcement with a mixture of uncured resin under vacuum conditions would release exothermic heat of at least 100°C without the use of external heat source which might affect the internal layer of the fiber reinforced material. To find mass diffusion analysis Fick's laws have been provided with a formula. The extension of the equations in Fick's law makes it possible for non-uniform solubility of the material to occur [24]. In order to measure moisture absorption behaviour, the specimen's weight is measured by immersing it upon to saturation period according to ASTM D5229 standards [25]. Processing defects such as low matrix content, lack of fiber impregnation, retained air bubbles inside the pipe or on the inner surface are causes of leakage of glass fiber reinforced tubes were noticed by Guillermina Capiel et al. [26] and his team and possible solutions to eradicate the failures were concluded by them. Yang et al. [27] investigated how water absorption and hydrothermal ageing influenced fibre surface on GFRP. Similarly other studies have done on ageing process and the methods to reduce the effects caused due to ageing process. The influence of water ageing on the mechanical properties of flax and glass fibre reinforced composites was done by Assarar et al [28]. The effect of water immersion effects in composites with different types of matrices was studied by Dell'Anno and Lees [29]. Studies have been done to eradicate the negative impact of the ageing process on GFRP pipes in the long time run. Studies were done to eradicate these failures and under research by the researcher. Due to the presence of water numerous internal defects and reduction in factors such as impact resistance and compression strength were detected by Intel nska and Guillaumat [30]. Most recently, Rafiee and Mazhari [31] have developed a general integrated procedure to evaluate long-term creep and predict long-term creep induced failure. Consisting of creep modelling, stress analysis and failure evaluation, the developed modelling is just in need of short-term experimental data of neat resin as the input.

3. FAILURE ANALYSIS

3.1 Air bubble penetration

As per work done, firstly failures were noticed during the process of Filament winding when a plastic-coated cloth is placed along the longitudinal section of the mandrel, air is vaguely trapped in the reinforcement and resulting in the formation of cells or holes in the wall. So during the forming and curing operations there is a decrease in the strength of the final piping and sometimes making it permeable and so the tubing will not be suitable for all kinds of uses. Also, because when a cloth type reinforcement is applied, it is well oriented into definite layers and is therefore likely to delaminate and also trapping of air in the reinforcement which consequently results in the production of tubing free of passage which promotes leakage and stress concentrations. Water molecules are spread in to fiber-matrix interface and to drifted along the fibers by surface tension reducing fiber-matrix bond. The figure-3 shows the failure caused due to the weepage caused by Air bubble formation inside the pipe.

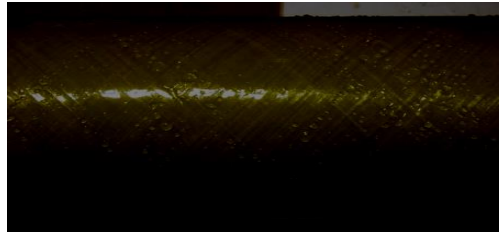


Figure: 3-Failure due the weepage caused by Air bubble formation inside the pipe

According to work done, The Coating resin which is applied must be free from air bubbles and dirt, so that the GFRP Pipe can with stand for long period of time. .

3.2 Moisture Formation

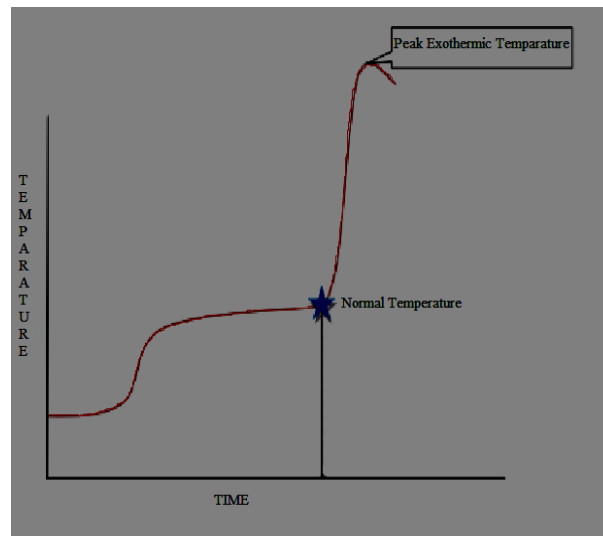
Secondly Moisture that is diffused into polymer matrix composites (PMCs) changed the mechanical and thermo-physical properties of the material and also due to Moisture and temperature increased the ageing process with the reduction of the mechanical performance of fibre, matrix and especially the fibre and matrix interface. Polymeric matrix becomes softened plasticised and swelled when subjected to humidity[33], More over can sometimes moisture can affect the composite material and the bonded joints by two mechanisms, deterioration of the adhesive bulk and deterioration of the interface due to the hydrolysis process. Under some cyclic hygrothermal degradation, thick composites pipes show a heavy stress concentration, a narrow region near to the Surfaces where holds the periodic moisture concentration [34]. The amount of moisture absorbed by the glass fiber reinforced composite pipes could be accurately predicted by plotting p.w.g versus t/L where t is the absorption time and L is the thickness of the sample material. The p.w.g is weight gained by the material due the absorbed moisture and is calculated as follows

$$\text{p.w.g} = \quad (1)$$

Where W_0 is the initial dry weight of the material and W_t is the weight of the sample at time t , [35] In addition, the diffusion coefficient and percentage of absorbed moisture can also increase with rises in immersed temperature and it improves the ductility of the matrix also. As per the study hydrothermal analysis is the preferred method to predict the moisture content and the movement of moisture before installation so that it can reduce the early degradation and service life can be increased. The temperature of the storage area is important in improving the life of the material. Base life is 6-8 months when stored at -18°C , by controlling the temperature and time moisture inside the GFRP Pipe can be eliminated.

3.3 Heat released by exothermic reaction

Thirdly, when the composite is wrapped with layers heat is released inside the wrapping layer after few months which is termed heat gained by exothermic reaction. The excess heat produced will depend on various factors such as number of layers wrapped across each fiber during filament winding, so due to heat it results in poor fibre-matrix adhesion which then undergoes fibre and matrix de bonding and splitting. In such failure, fibres which are destroyed are located at any place along the specimen. By exothermic reaction in the pipe, thermosetting matrix problems such thick laminates formation, matrix distortion and few other small problems are noticed. In some cases during Manufacturing high exothermic temperature is produced within the layers of the fiber cloth which caused burning and chemical loss in the resin, to control this filler was added. The time to reach highest exothermic heat is also reduced with increasing filler amount, thereby reducing the cure cycle. The graph below shows time versus temperature during curing operation of the GFRP Pipe.



Graph:1-Time vs Temperature during curing operation for optimum temperature during manufacturing process of Glass fiber reinforced pipes [36]

Sometimes due to high exothermic temperature degradation of resin may occur hence mould cooling is necessary to reduce the heat. The fiber-matrix adhesion reduction which is caused due to heat release will decrease the load transfer from one phase to another degrading the mechanical response of the pipe [37].

4. CONCLUSION

A Comprehensive work was done on the failures of GFRP Pipes and considerable efforts have been made to find the failures of GFRP Pipes. They are suitable precaution methods to control the failures to some extent according the work done:

1. Air bubbles in a surface of the pipe can reduce its strength and may also affect its corrosion resistance properties. Air bubbles in the corrosion liner can be more damaging than those in the structural layer, So try to eliminate the air bubbles cleanly which are residing in the liner. By applying epoxy resin laminate in appropriate ratio can decrease the possibility of snagging air bubbles formation and will make sure that the glass will be pervaded from the bottom.
2. Avoid aggressive mixing of the resin and hardening material which may produce air into resin. However, be sure the catalyst is mixed finely into the resin.
3. The resin mix can be prepared at least one day ahead so that the entrapment of air bubbles escape before the lay-up begins.
4. Mandrels should be applied with resin first, then apply glass, and roll it into the resin. Air bubble problems are unavoidable when resin is applied to dry glass.
5. Roll the laminate from the centre of the mandrel to the edges of it. Roll steadily, but not too hard. Excessive force might break the existing bubbles and make them more difficult to remove.
6. Eliminate all the bubbles from one ply which has been used before starting on the next process.
7. Thoroughly clean the rollers between uses.

When it comes to the point of moisture the possible solution would be , using an outer layer of glass fiber yarn and resin in normal foam insulating material to form a continuous moisture-impervious cover, said outer layer of glass fiber yarn being wound over the ends of the foam insulating

material to fully enclose the foam insulating material. The absorbed moisture may lead to the reduction of bending strength due reduction of mechanical properties after moisture absorption. Finally, In the case of failure due to creep induced failure with in the GFRP tubes during long time run so to reduce the failure, analysis should be done by creep modelling, stress modelling and failure evaluation by the designers before implementing it at the work station. In spite of the efforts in the wide range of study done, there are still some issues which are not found out and may be considered for the future studies.

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Corrigendum: Failures Analysis of E-Glass Fibre reinforced pipes in Oil and Gas Industry: A Review

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Page 6:

Formula (1) is incorrect. The correct formula should read:

$$p.w.g = \frac{W_t - W_o}{W_t}$$

Figure 2:

The correct version of the Figure 2

