

Deterioration of Glass Reinforced Plastics and Impact on the Effective Life Span

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Abstract

The odour containment covers at Beenyup waste water treatment plant are made using glass reinforced plastic (Sandwich Construction). It is generally expected that the lifetime of the GRP is 25 years, however concerns have been expressed regarding the structural integrity due to the exposure to harsh Western Australian climatic conditions, particularly UV exposure and the corrosive atmosphere in the waste water treatment plant. The objective of this project is to alleviate this concerns by developing a method to assess the condition of the GRP covers and determine the remaining service life. The changes in material property over time were determined through mechanical testing. Additionally, finite element modelling was used to identify any structural design issues with current covers.

1. Introduction

In Early 2000s Water Corporation deployed odour control system at its waste water treatment plants (WWTP). As a part of this system, Grit Tanks, Primary Sedimentation Tanks (PST), Aeration Tanks, foam channels, mixed liquor channels and Dissolved Air Flotation Tanks were all covered with Glass Reinforced Plastic (GRP) odour containment covers (Water Corporation, 2005). It is generally accepted that GRP has an effective lifetime of 25 years; however no holistic degradation model is available to support this claim and/or to predict the degradation of the GRP over its lifetime. The uncertainty about the structural integrity of the covers represents a high risk situation, as it is currently not possible to predict when the covers have become unsafe to walk on. An unexpected failure could result in an injury to personnel when performing routine tasks. In extreme cases it could result in hospitalisation or a fatality. Additionally, conservative renewal strategies to prevent injuries due to the lack of effective information can result in poor life cycle management, incurring additional cost to the organisation.

The current state of the art with regards to the service life of the GRP is that the material properties should not significantly degrade over 25 years. It is known that the material properties of GRP degrade over time due to environmental effects such as, are moisture, alkaline environment, thermal effects, fatigue, creep/relaxation and UV radiation follows (Liao, et al., 1998; Karbhari, et al., 2003). However, the extent and the rate of degradation remains unknown. Additionally, for most composite structures one normally does not encounter material failures (e.g. yield stress) but structural failures such as buckling and delamination (Barbero, 2013).

The objective of this project is to develop a method to assess the condition of the GRP covers and determine the remaining service life. Following the completion of the project it is expected that a condition monitoring program will be developed and implemented. This will provide more data about the degradation of the materials. This project will allow for proactive asset management and reduction of costs associated with repair or replacement; and the reduction of risks and increase in safety is in line with the Water Corporation's Zero Harm policy.

1.1 Cover Material and Construction

The covers are a sandwich construction comprised of polyurethane foam core materials with a GRP skin (Transfield RP/C, 2002). Sandwich construction is very suitable and amenable to the development of lightweight structures with high in-plane and flexural stiffness. The bending and in-plane loads are carried by the thin skin/facing and the core helps to stabilize the facings and provides the flexural stiffness, out-of-plane shear and compressive resistance (Daniel, et al., 2002). The overall performance of this structure will depend not only on the properties of the facings, but also on the core and the adhesive bonding of the core to the skins, and the geometrical dimension.

The GRP skin is consists of isophthalic polyester resin and glass reinforcement fibre (Transfield RP/C, 2002). The reinforcement fibres are predominantly E-class glass fibres, in the form of 450 g/m² chopped strand mat (CSM). E-glass is a general purpose grade of glass fibre and is the most widely used type of glass. It offers high tensile strength and excellent durability characteristics (Estrada & Lee, 2014). The isophthalic resin used in the covers is known to have better chemical resistance (particularly to acidic environment) than general purpose orthophthalic polyester (Pai & Kamath, 1997).

2. Methodology

Due to the sandwich construction of the covers, the panel integrity is not only a function of material properties but also the physical features (e.g. cracks, seam joints etc.). The finite element modelling will be used to determine if the covers are safe to walk on. Commercial finite element solver ANSYS will be used for this task. Additionally, mechanical testing will be conducted to determine the extent of degradation of material properties.

2.1 Finite Element Modelling

The objective of the finite element analysis is to check the design of the covers. The analysis will particularly focus on physical features such as joints between top and bottom layers of the skin, contact between the GRP skin and foam core.

The finite element model will be constricted at a meso-level in order to obtain stress and strain distributions. In order to do this laminate stacking sequence (LSS) will have to be provided. This will include elastic properties of each lamina, as well as thickness and fibre orientation of every lamina (Barbero, 2013).

The Elastic properties of each lamina will be calculated using Halpin-Tsai model (Barbero, 2010)

$$E = \alpha E_g v_g + E_r v_r \quad (1)$$

Where,

E - Elastic modulus of the lamina

E_g - Elastic Modulus of the glass fibre

v_g - Volumetric fraction of glass fibre

E_r - Elastic Modulus of the resin

v_r - Volumetric fraction of the resin

α - Parameter that depends on efficiency of the reinforcement ($\alpha = 0.3$ for CSM)

The analysis will be carried out using the commercial finite element solver ANSYS. The covers (skin and foam) will be modelled using quadratic shell (SHELL281) elements. SHELL281 is a suitable element type for this analysis as it suitable for analysing thin to moderately thick shell structures. It is suitable for layered application for modelling sandwich construction.

2.2 Mechanical Testing

The following mechanical tests will conducted to determine the extent of material degradation. For this a 10 year old cover is used which is no longer serviceable, due to delamination. The following mechanical testing are prescribed: (1) Tensile strength of the GRP skin, (2) 3 point bending test of a cover sample, (3) Barcol Hardness Test and (4) Compressive test of the foam core

All the tests will be conducted on an INSTRON 5982 machine.

2.2.1 Tensile Tests

The tensile test will be conducted on the skin of the covers. Since the top and the bottom skin are exposed to different environment and hence, different degradation processes, the samples from both the top and bottom skin will be tested.

This tests will be conducted in accordance to the AS1145.4-2001. The fibre reinforcement arrangement used for the covers is chopped strand mat (CSM). CSM is made up of chopped strands of glass fibre laid randomly and held together with a binder or stitching. Due to the random orientation of fibres it is assumed that CSM is isotropic (Barbero, 2010). Hence, the anisotropy of the material isn't considered for the tensile test.

The samples are tabbed at the end for better gripping and load introduction.

The dimensions of the tensile test specimen is listed in Table 1.

Dimension	Value	Unit
Overall Length, L_3	250	mm
Gauge Length, L_0	50	mm
Length of the end tabs, L_T	50	mm
Distance between the tabs	150	mm
Thickness, h	2	mm
Thickness of the end tabs, h_T	1-3	mm

Table 1 The dimensions of the tensile test specimens.

2.2.2 Three Point Bending Test

Three point bending will be performed on the sandwich beam. ASTM C393 is used as guideline for this test. Test specimen for this test will be 560 mm long and 70 mm wide. The span length to thickness ratio for the test will be 13.89.

2.2.3 Compression Test

Uniaxial compression test will be conducted to determine the material properties of the foam. Since, the thickness of the skin is much smaller compared to the foam, the skins will not be removed for the test. The compression test specimen will be 40 mm long and wide.

2.2.4 Barcol Hardness

The hardness of the skin will be measured using barcol hardness. The barcol Hardness test is carried out using a Barber-Coleman Impressor. This device is portable and lightweight and allows for non-destructive testing of the specimen to determine the hardness of the sample. The determination of Barcol hardness as a part of inspection is a standard practice in FRP/GRP industry.

One of the objectives is to determine a relationship between the hardness and mechanical strength of the covers, such that barcol hardness can be used as an indicator of material degradation for condition assessment.

3. Results and Discussion

3.1 Recurring mode of failure

From the review of archival information it was noted that the most prevalent type of failure observed is the delamination of top and the bottom skins of the cover (See Figure 1). The location of this crack is also shown in the drawing in Figure 2. The recurring mode of failure is indicative of intrinsic stress concentrations. The delamination is likely the result of insufficient (2 mm thick) overlap between the top and the bottom skin of the cover. This inference will be tested using finite element analysis.

Additionally, the covers are formally classified as non-trafficable roofs under AS1170 and AS1657. The covers are designed to carry some occasional maintenance traffic. This classification may not be true for GRP covers on the channels which are more frequently (on daily basis) trafficked.

4. Conclusions and Future Work

Current industry opinion regarding material degradation in GRP assets is that the material properties don't degrade significantly over 25 years. This hypothesis will be assessed by the mechanical tests being conducted on covers which have been in operation for over 10 years.

The historical evidence hints that the covers were insufficiently designed, making them vulnerable to delamination failures. This hypothesis will be tested through finite element modelling to determine any stress concentrations in the current design. Alternative design solutions will be proposed to address any design issues.

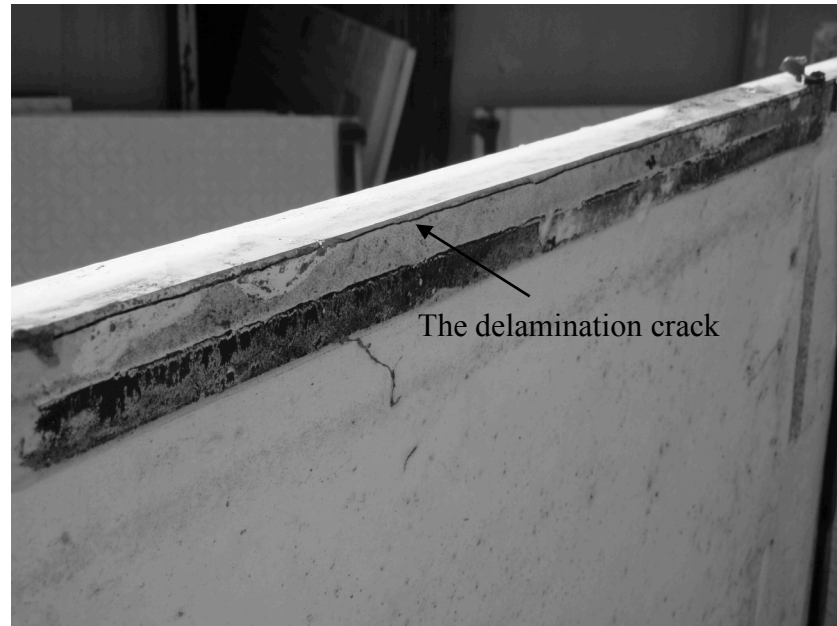


Figure 1 The Delamination Crack

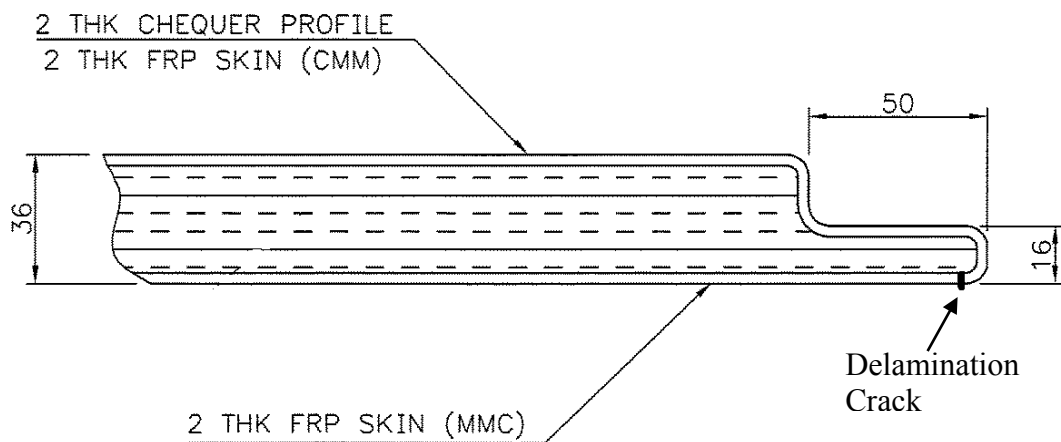


Figure 2 Schematic diagram of the Cover showing the crack location

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