Case study

Investigation into the Failure of an FRP Vertical Cylindrical Tank

A glass fibre tank to be used for the treatment of waste water was supplied to a waste water treatment works in the UK. After installation, the tank developed a leak. It was repaired but continued to leak. The FRP vertical cylindrical tank for chemical storage use was designed to the following design criteria.

Pressure	Atmospheric	
Temperature	Operating: Ambient	Design: 30°C
Cycles	Operating: 1000	Design: 1000
Contents	Ferric Chloride	
Specific gravity	Operating: 1.47	Design: 1.47
Capacity	25,000 litres	
Basic wind speed	46 m/s	
Post cure	3 hours @ 80°C	
Liner material	Isophthalic	
Structure resin	Orthophthalic	
Finish	Orthophthalic	

The method of manufacture was mechanised spray.

Inspection of theTank

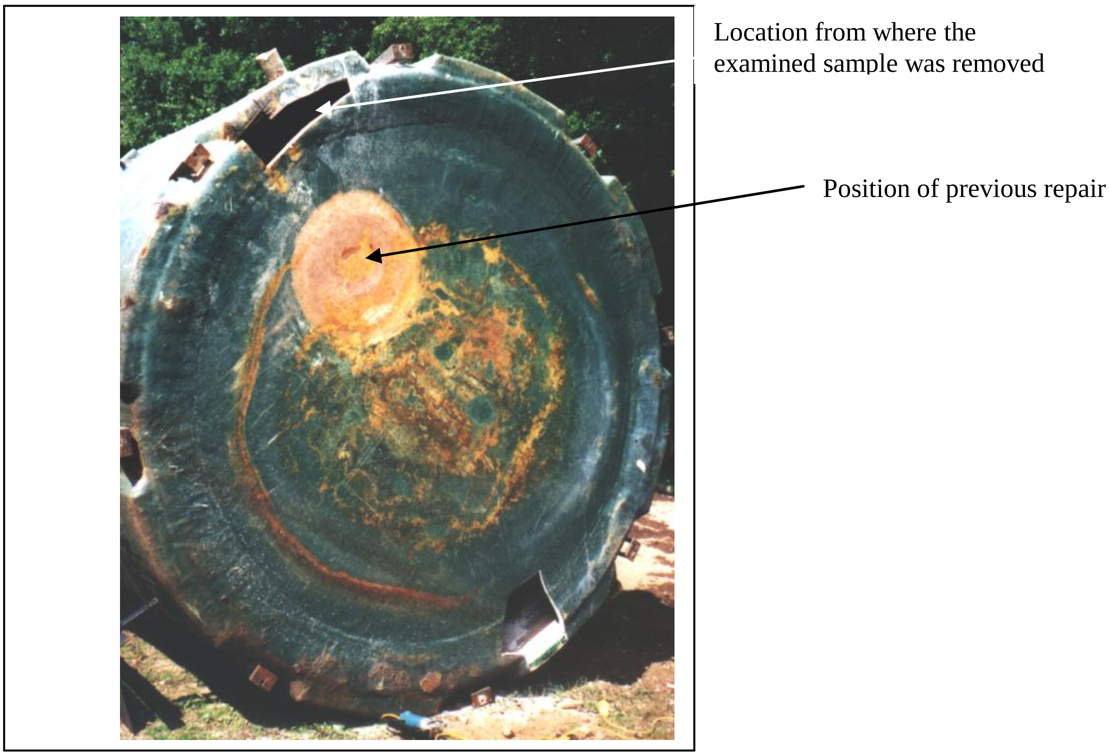
The tank had been unbolted and lifted from the vertical onto its side to allow access to the base. Internal access was prohibited for safety reasons.

The vessel was a vertical cylindrical tank with an access ladder to the top with insulation over the cylindrical portion. The vessel height was 4m and diameter 3m. The base of the vessel had a knuckle radius of 45 mm.

Fig 1 General view of vessel

An area of the base of the tank approximately 600 mm diameter had been previously repaired. The repair laminate appeared sound and adequate. (The position of the repair is shown in Fig 2).

Fig 2 Vessel laid horizontally, general view of base.



Two cracks could be clearly seen in the base. It was noted that they were diametrically opposed to one another and followed an approximate circumferential line within about 150 mm of the vessel wall. Sample laminates were machined from the area of the crack to allow closer inspection and analysis

Fig 3 shows the exterior view of base of the tank before being sectioned showing the extent of the crack. The crack was approximately 600mm long on the inside of the tank and 200mm long on the outside.

Fig 3 Exterior view of base of the tank
Bottom surface (external, in contact with the base) before being sectioned showing the extent of the crack.

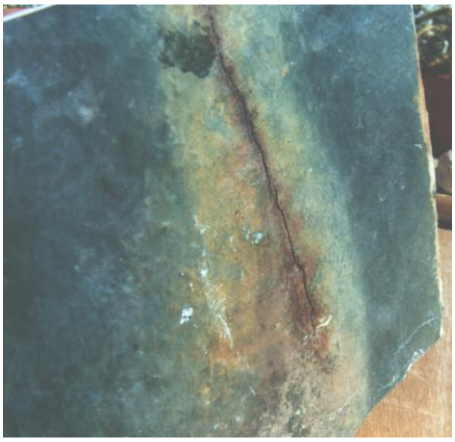
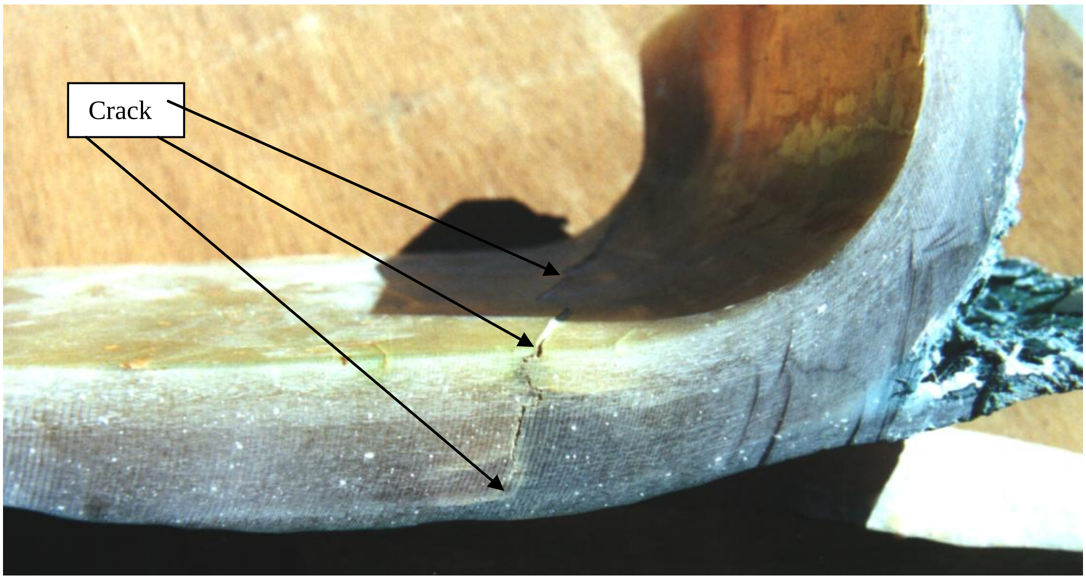


Fig 4 is a section through the base to wall knuckle radius and Fig 5 shows part of the crack in the inner surface of the tank.

Fig 4 Examined sample – section through the base to wall knuckle radius.

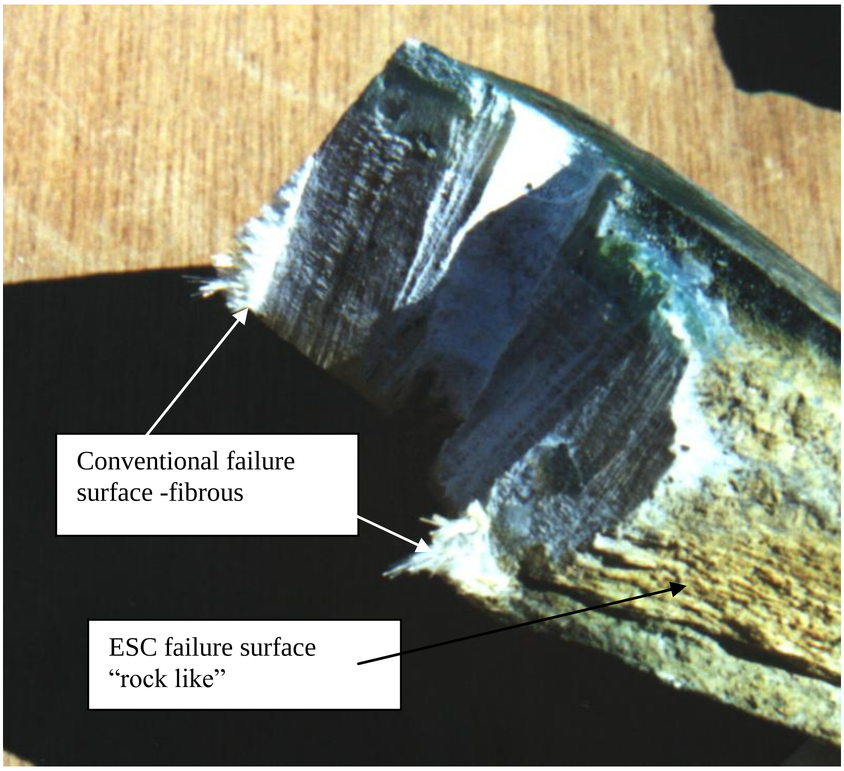


The sample was parted in two by hand, (an action which should have been impossible), to reveal the failure surfaces. They are shown in Fig 6. Inspection of this sample revealed two distinct zones (see Fig 7) one of which was fibrous and the other which was "rock" like, without any fibre protruding from the surface. The fibrous type surface is well known and to be expected from the failure of a random laminate. It was this material which was keeping the laminate together. It is apparent that the two failure types are significantly different.

Fig 5 Removed sample showing part of the crack

Fig 6 showing both fracture surfaces

Fig 7 Contrast between the two types of failure showing the contrasting "fibrous" and "rock like" failure surfaces.



Tests

Several tests were carried out:

- Flexural Modulus
- Flexural Strength
- Strain at first break (Gel coat strain to failure)
- Glass Content
- Barcol Hardness

Flexural strength and modulus were both within the range to be expected for the glass content determined. Barcol hardness was measured to check for under cure. The values were low for a post cured laminate but gave no serious cause for concern.

The strain to failure of the gel coat is particularly important in the corrosion resistant layer of a laminate in order to minimise the likelihood that environmental stress corrosion will occur.

The maximum allowable strain is generally required to be the lower of either 0.1 of the resin strain to failure, or 0.2%. i.e. the strain to failure of the resin must be at least 2%.

The measured strain to failure of the gel coat was found to be in the range 0.83% to 1.29 %. This implies that it was out of specification. However the strain to failure of the gel coat is reduced during the curing process. The laminate shrinks less than the gel coat when released from the mould and therefore maintains a strain level in the gel coat and effectively reduces the strain which is available.

The test results would not give cause for concern if the contents of the vessel were benign to the reinforcement fibres. However the contents are in fact aggressive to the reinforcement fibres.

The effect of Ferric Chloride solution on "E" glass

"E" glassfibre filaments were immersed in a sample of the contents of the vessel (Ferric Chloride solution) and SEM micrographs were taken of the surface after several days' immersion.

This work was carried out to determine, by inspection of the fracture surface, if Environmental Stress Corrosion was plausible and to assess the time scale of any such attack.

Fig 8 is an SEM micrograph of the surface of glass fibre ("E" glass) filaments before immersion. They aew simple cylindrical objects devoid of features.

Fig 8 glass fibre filament before immersion

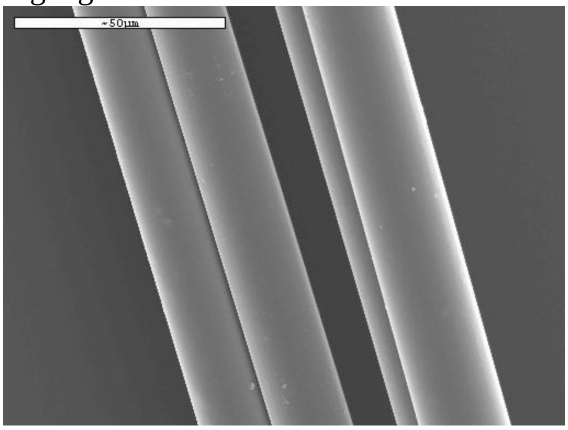


Fig 9 "E" glass filament (1000x) after 7 days immersion in Ferric Chloride solution

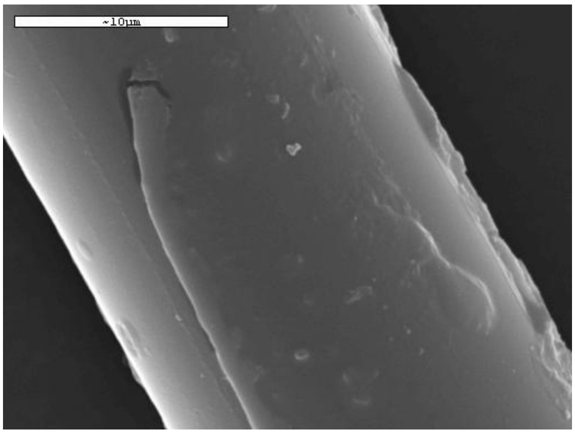


Fig 9 is an SEM micrograph of the surface of an individual glass fibre ("E" glass) filament which has been immersed in a sample of Ferric chloride solution for 7 days. (The sample of Ferric chloride solution was previously removed from the vessel). It can be seen that the filament has been attacked. It is apparent that it has been severely degraded by the effects of the Ferric chloride. A defect in the surface of a glass fibre has a catastrophic effect on its strength. We can conclude that a crack in the resin system which allows the Ferric chloride to gain access to the glass fibre reinforcement will attack the glass and prevent the normal crack stopping mechanism from operating. The crack will therefore continue to propagate through the laminate as long as the stress is applied and the aggressive environment has access to the reinforcement fibres.

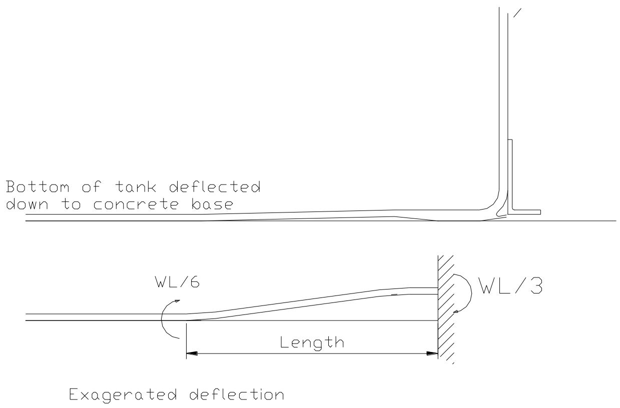
Possible causes of the initial crack

There are several possible reasons why the initial cracks were created.

1) Inappropriate support of the external profile of the base of the tank.

There is a step in the base of 10mm. See Fig 10 The base is sufficiently large that most of it's area easily deflects to come into contact with the concrete support. However calculations have shown that around the periphery there is a ring 208mm wide that remains unsupported. The stress and the strain in this region were sufficiently high to have resulted in surface cracking.

Fig 10



2) Inappropriate bolting down

Inappropriate bolting down can induce a high local bending moment in the vessel which may create a crack in the gel coat surface of the vessel. E.g excessive torque applied to the holding down bolts without the necessary shims in place.

Incorrect shim heights.

“over-shimming” of the support feet causing the tank to be effectively unsupported. In such circumstances filling of the tank would cause the base to rapidly deform to contact the plinth, but there would be very high bending in the cylinder/base junction near to the feet.

The fact that the two cracks are diametrically opposite to one another is a strong indicator of an inappropriate bolting down procedure.

3) Water fill whilst the tank was fully shimmed and bolted.

4) Accidental damage during transport, installation or testing.

Conclusions

The vessel failed due to Environmental Stress Corrosion although the construction of the vessel from purely structural requirements was adequate.

The likely cause of the tank leakage was as follows:-

- An initial crack or cracks was created in the gel coat of the inner surface of the tank.
- The crack allowed the contents of the vessel to gain access to the reinforcement fibre of the laminate.
- The contents of the vessel (43% ferric chloride), although not particularly aggressive to the resin system, had an aggressive capability to the reinforcement fibres such that the fibres were degraded and lost a significant proportion of their strength.
- As the crack was under stress due to the hydrostatic pressure in the vessel it had the propensity to continue to open further. Thus exposing more glass fibre to attack and continuing the process. The process would have continued until the crack was large enough to produce total catastrophic failure of the vessel.

The most likely cause of the initial cracks was inappropriate bolting down. But whether this was due to "excessive torque" or "over shimming" isn’t known.

Appendix

Environmental Stress Corrosion

Environmental stress corrosion cracking occurs when an environment which is aggressive to the reinforcement gains access to it. Normally the reinforcement (glass fibre in this case) is protected from the environment (in this case ferric chloride) by the resin system. All polymers allow liquids to permeate through them to a small degree and may degrade the reinforcement. Thus the life of such a laminate, although probably many decades, is never the less finite. The degree of degradation is a function of factors such as temperature; time exposed, rate of permeation, type of aggressive medium and of course if there is a crack in the laminate which would allow direct access to the reinforcement.

Cracks in composites are not uncommon they range from a very simple scratch to very obvious damage which might be caused, for instance, by impact. Normally they are arrested when they reach a reinforcement fibre. However if the environment, which then has access to the fibre reinforcement, is aggressive to it then catastrophic failure can occur. This could result in loss of life and serious damage to other equipment.

It is essential that the design allows for certain circumstances to occur. These are very disparate and include the possibility of a trivial crack occurring in the gel coat surface of the laminate. Cracks, scratches, scrapes and minor discontinuities are all common occurrences in vessels of this type. They are undesirable but they are to be expected.

Thus it is for the designer to have considered the effect on the structural integrity of the vessel of a minor crack occurring. If the contents of the vessel are benign to the glass fibre (which is generally the case) then it is of little consequence. But if the contents of the vessel are aggressive to the glass fibre reinforcement then steps should be taken to ensure that either a minor crack cannot occur or that if it does occur that a barrier is in place to prevent failure.

Options available are, for instance, the use of gel coat and barrier layer resins with high strain to failure and or the use of one or more layers of synthetic veil or a corrosion resistant grade of glass fibre if necessary.