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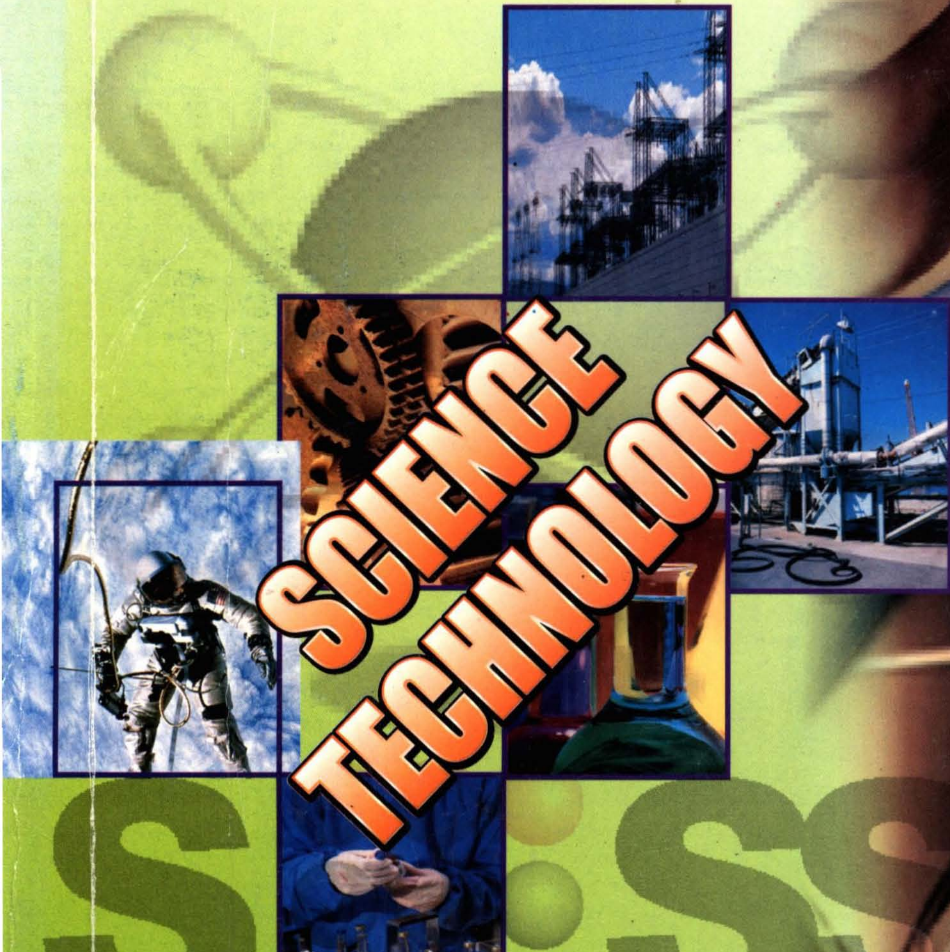

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Failure Investigation of GFRP Water Storage Tank: A Case study at IKBN Jitra, Kedah

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ABSTRACT

This paper described a failure investigation of 13,200 gallons GFRP water storage tank that had happened at Institut Kemahiran Belia Negara (IKBN) Jitra, Kedah. Based on the preliminary observation, the failure started at the outlet flange hole where the water propagated inside the tank's wall and cracking the laminated composites. Four standard tests have been performed to investigate either the GFRP material or other factors that caused the tank to burst. Then, comparisons have been made with SIRIM's standard testing on fabricating water storage tanks and the results show that the material passed the minimum requirements of the tests. At the end of the investigation, the major failure that had been concluded was that the fabricator is not using a good 'hand-lay up' technique to manufacture GFRP water storage tank according to the design specifications. These investigation results will bring advantageous to the researchers and water tank fabricators in seeking the proper fabrication of GFRP water storage tanks with high mechanical performance, very robust and safe to be used in the residential areas.

Keywords: *GFRP water storage tank, failure modes, manufacturing process.*

Introduction

The GFRP water storage tank at IKBN Jitra, Kedah was built in 2001 on top of a 40 feet high tower for the purpose of saving and providing water to IKBN Jitra, Kedah. The physical size of the tank is given in Table 1. The objective of this paper is to investigate the cause of failure of the GFRP water storage tank at IKBN Jitra.

Table 1. Physical Size of the Water Tank at IKBN Jitra, Kedah.

Capacity	13,200 gallons
Diameter	4.5 meter
Height	3.8 meter
Position	40 feet (tower)

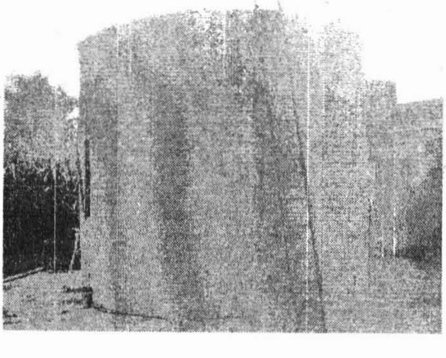


Fig. 1: Reconstructed Tank at Atostech Factory

On 1 August 2004, after two weeks after the tragedy, the failed tank has been reconstructed at Atostech Fibreglass Sdn. Bhd factory by the investigators to inspect and examine the cause of failure. Figure 1 shows the reconstructed tank at the factory. However, the base of the tank was not brought from the site. From the inspection done, it can be seen that the source of the tank failure was the malfunction of its outlet flange hole. The analogy of the tank failure; how the tank failed and fell from the tower is also shown in Figure 2. This caused the tank wall to crack vertically upward from the hole to the top of the tank and downward to the corner of the wall at the bottom of tank as shown in Figure 3.

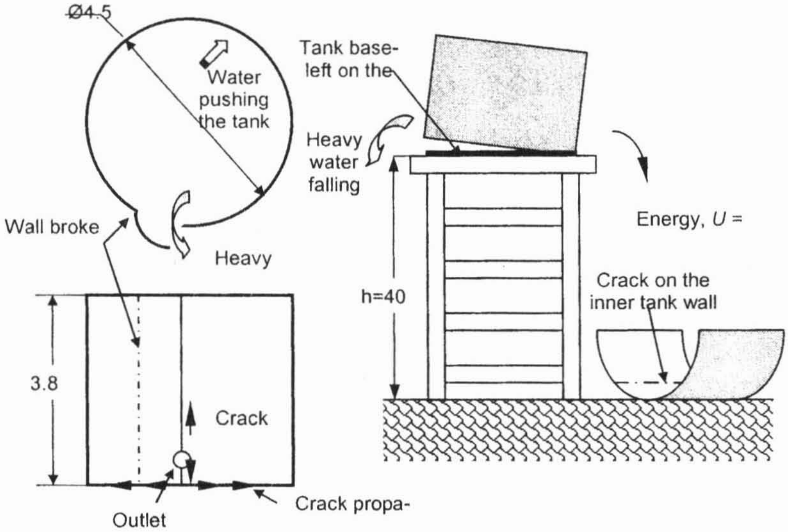


Fig. 2: Analogy of Tank Failure

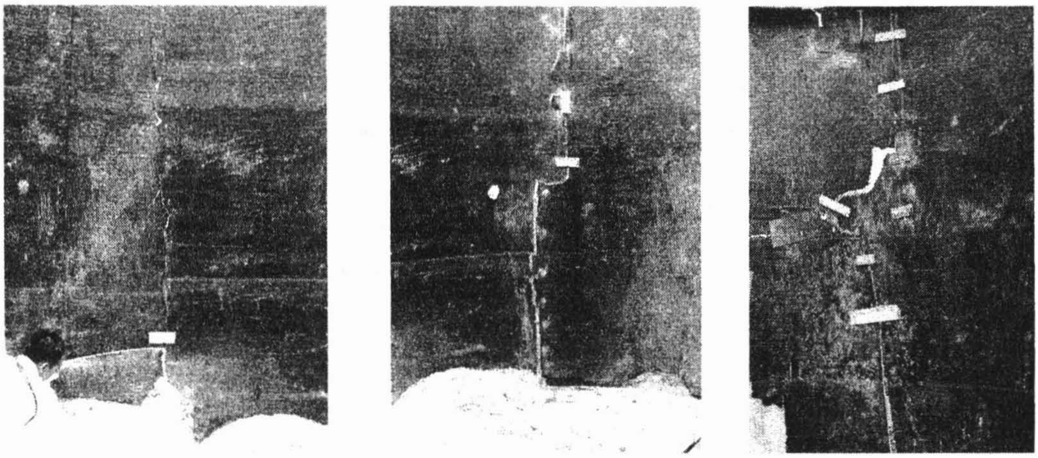


Fig. 3: (a) Net Section Failure, (b) Inner Wall Fracture, and (c) Failure Caused by the Crash from Falling.

As the outlet flange hole crack vertically, upward and downward, the hydrostatic pressure of the water caused the cracks to spread quickly. This continued until the high pressure fractured the tank wall vertically. At the same time, the crack spread to the corner of the tank floor because it became the tank's highest concentration point. This causes the thrust force of the tank to exist, with opposite direction from the water flow, thus causing the wall to fall from the tower, leaving the base on the tower.

The wall experienced a massive crash and cracked the inner wall of the tank. This is due to its rounded shape, plus the weight on the whole tank wall. Net Section Failure refers to tensile failure of a holed material. Crack until disconnected on the tangent hole occurred in the direction perpendicular to the tensile stress on the material. This phenomenon is shown in Figure 4.

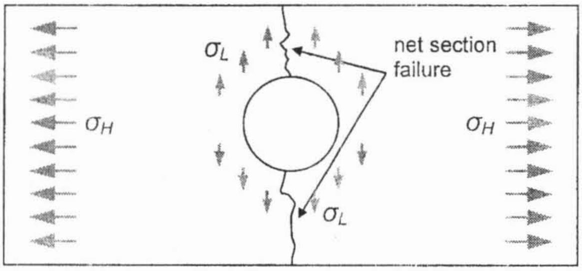


Fig. 4: Net Section Failure

In the case of this tank failure, the hole on the tank wall that was used as a outlet flange hole was the caused of the overall failure of the tank structure. Generally, stresses that exist in a water tank is shown in Figure 5. Tension in circular direction, σ_H is two times the the tension in vertical direction, σ_L. Thus, only stress in circular direction will be given attention in tank failure analysis discussed further on.

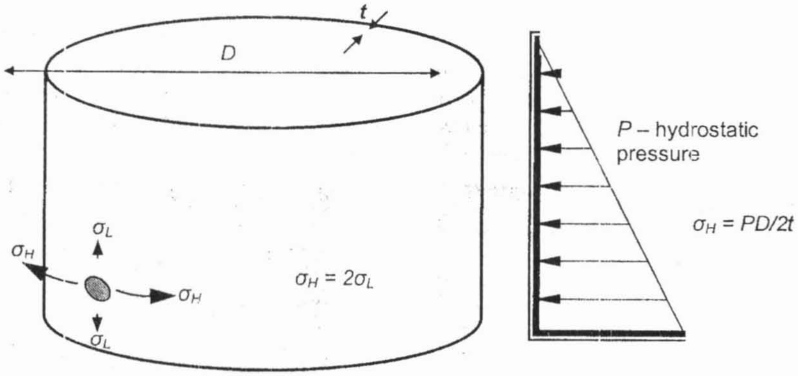


Fig. 5: (a) Tension inside Tank Wall, and (b) Hydrostatic Pressure of the Water produced Tension on the Wall

Causes of a GFRP Tank Failure

Usage of composite materials inside a product or a structure requires a deep comprehension, especially the nature, strength and behavior of the material on the load. For a GFRP tank, attention should be given when making flange holes on the tank for outlet, inlet, overflow and scour drain pipes. This is because these holes if not handled correctly can be the cause for a GFRP tank failure.

Tension Tangent

Maximum stress tangent existed on outlet flange hole tangent as shown on Figure 6. The stress on this tangent was maximum because both tension from the circular and vertical direction concentrated here. Thus, any crack on the hole's tangent can spread quickly because of the concentration of these stresses. In composite structure design, loss of a part of a body that holds load must be bond with several layers that has the same strength as the discarded part. The tank did not have any bonded layer around the hole on neither outer nor inner side. This caused the concentrated stress on the tangent hole was withstand only by the original thickness of the tank.

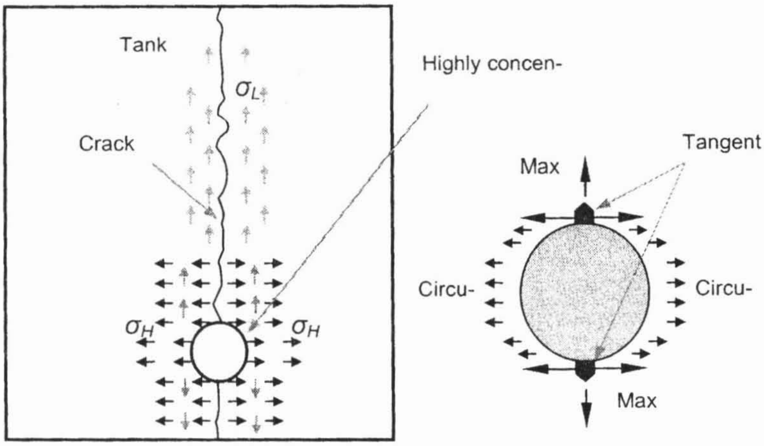


Fig. 6: Stress on the Tank Hole

Exposure to the Environment and Unsmooth Cutting

Since outlet flange hole is the cause of whole tank failure, detailed examination is done on the hole. The result showed that the cutting section was not treated properly to avoid moisture effects. Thus, the cutting section was exposed to water and moisture. Because composite materials are made up of glass fibre, delamination occurred when raisin reacted with water. Slowly, this process caused the area around the tank hole became weak and the strength to hold load decreasing. Figure 7(a) shows evidence of delamination around the outlet flange hole.

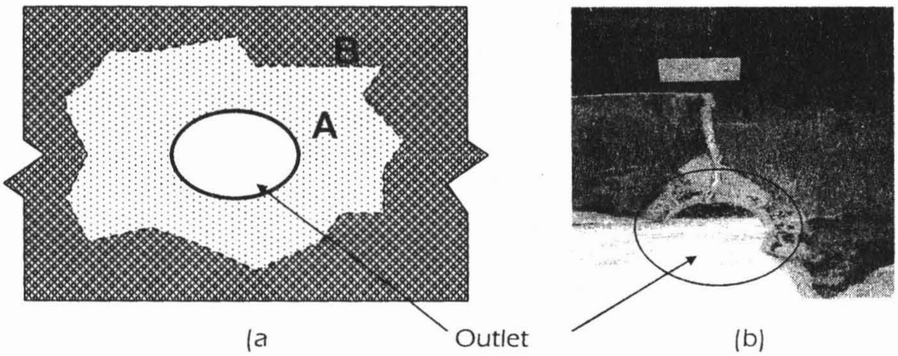


Fig. 7: (a) Delamination around the Outlet Flange Hole (b) Unsmooth Cutting of the Outlet Fange

Water and moisture that penetrated and spread through fibre glass quickened the delamination process, thus making it not able to hold the stress concentrated around the hole, especially on the tangent. Figure 7(b) shows untreated hole surface after cutting was made. In addition to that, messy cutting, and unsmooth surface becomes the factor encouraging the cracks.

Assemble of Tank Components

From observations, assembling between tank components was not laminated again on the outside for whole tank structure integrity. Lamination on the outside of connection ensures stress brought inside tank wall by hydrostatic pressure is withstand by inside lamination. Stress is transform from shear strength properties between laminate on the connection. Without lamination on outside of the tank wall, the water hydrostatic pressure was only withstand by laminate inside the tank wall. Therefore, it is very important to make sure the whole tank structure integrity is not affected because water tank is a structure that always withstand continuous load. Every part plays role to withstand stresses that exist in tank structure. Figure 8 shows assembling method between tank components on the outer side of a tank.

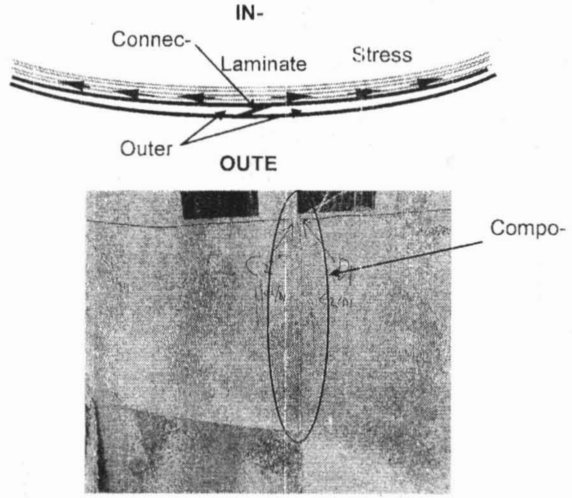


Fig. 8: Assembling Method of Outer Tank Components that are Not Laminated

Evaluation of Failure Factors

Test samples was taken 0.5 m around the outlet flange hole and cut according to size depending on the tests conducted. Four tests were carried out, which were tensile test, bending test, shear test and burn-out test.

Sample Location

The location of samples for all tests is around outlet flange hole, as illustrated in Figure 9. Samples taken must be closest to the cause of failure, which was outlet flange hole to attain actual depiction of the condition of laminate on that area. Other than that, the position of the thickest is 0.5 m from the tank base to the floor. This position suffered highest hydrostatic pressure, thus the most critical area. Samples were divided into four parts which are A, B, C and D. B and C were the areas closest to the outlet flange hole.

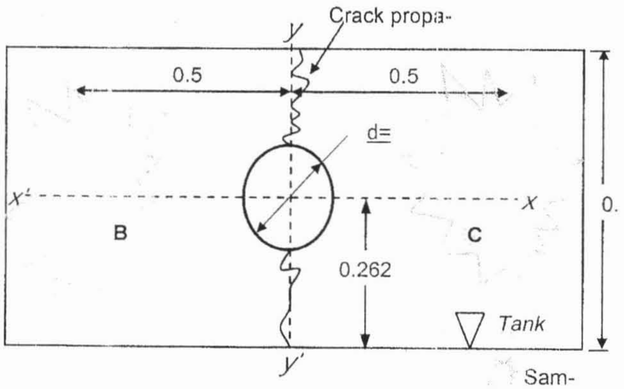


Fig. 9: The Location of Samples from the failed 13,200 gallon GFRP Tank

Tensile Test

Tensile testis was done to acquire the value of maximum stress strength for tank wall laminate. To perform the tensile test, ASTM D 3039 standard was applied byusing DARTEC Universal Testing Machine. Figure 10 shows the tensile test.

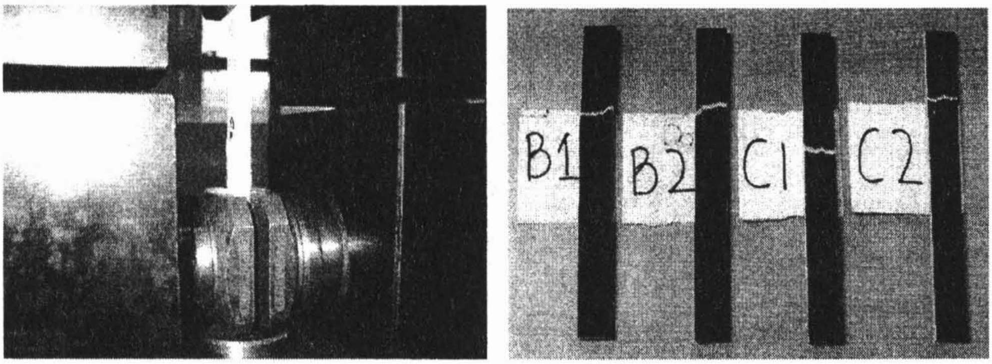


Fig.10: Tensile Test using DARTEC Universal Testing Machine

From the tensile test done using DARTEC machine, the results obtained are as shown in Table 2.

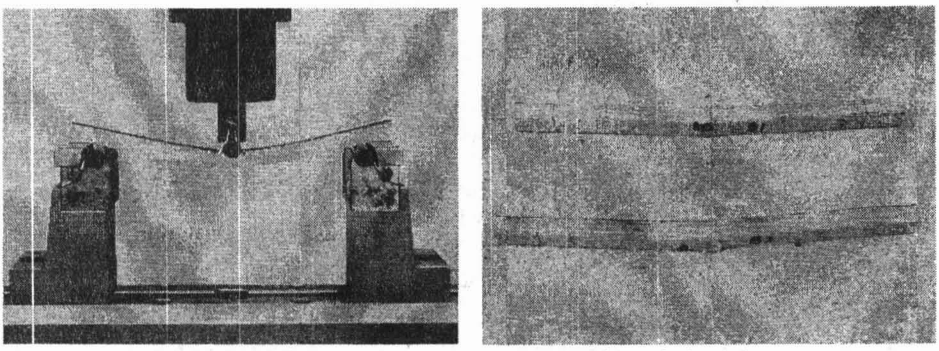
Table 2: Tensile Test Results

Sample	t_{avg} (mm)	w_{avg} (mm)	A (mm^2)	F_{ult} (kN)	σ_{ult} (MPa)	Failure Mode
B1	8.987	25.03	224.92	21.2	94.26	Tensile
B2	9.247	24.25	226.09	22.0	97.31	Tensile
C1	8.603	25.59	211.52	19.0	89.83	Tensile
C2	8.813	23.63	208.25	20.0	96.04	Shear
Average tensile					94.36	

From the tensile test conducted, pure tensile failure was seen on specimens B1, B2 and C1. Specimen C2 showed not only tensile failure but also shear failure. Shear failure occurred on WR and CSM laminate, which already has low shear force. However, the tensile strength of this laminate was high which was 94.36 MPa and exceeded the minimum value specified by SIRIM's tensile test which is 63 MPa. Thus overall, laminate for tank wall was safer than the benchmark minimum level.

Three Point Bending Test

Three point bending test was done to obtain maximum bending strength of tank laminate. The ASTM D790 standard was used in this test with the following conditions; span length, (L = 150 mm), crosshead speed = 4.1 mm/minute and using INSTRON 4206 series Universal Testing Machine. Figure 11 shows the bending test done with INSTRON machine.



(a) During failure (b) Failed specimens

Fig. 11: Bending Test and Failed Specimens

Table 3. Bending test results

Sample	Yield Displacement *(mm)*	Yield Load *(kN)*	Yield Stress *(MPa)*	Yield Strain *(mm/mm)*	Young Modulus *(MPa)*
B1	12.98	0.5879	120.2	0.0316	5860
B2	12.29	0.6274	130.2	0.0294	6321
Average	**12.64**	**0.6077**	**125.2**	**0.0305**	**6091**

From output of the INSTRON machine, the data in Table 3 was obtained. It can be seen that failure happened to the lower part of the specimen that suffered tensile and on the upper part of the specimen that suffered compression. Maximum bending strength obtained was higher than minimum bending strength value specified by SIRIM, with averaged value 125.23 MPa, compared to 10 MPa, while modulus value was 6091 MPa compared to 4830 MPa. Overall, laminate of tank wall was in good condition with strength higher than the minimum value specified by SIRIM.

Lap Shear Test

Lap shear test wad conducted to obtain the shear strength between laminate layers to evaluate the ability to withstand shear force between the different stiffener layers. Procedures in this test followed the BS 4994: 1987 testing standard. The shear test was done following the BS 4994: 1987 (Appendix B9) testing standard with the following conditions; shear speed = 0.1 kN/s and using DARTEC M9500 Universal Testing Machine. Figure 12 shows the condition during testing and failed specimens.

From output of the DARTEC Universal Testing Machine, the data in Table 3 was obtained. It can be seen that failure occurred at laminate between WR and CSM because these layers are in between the cuttings. Maximum shear strength obtained was higher than minimum shear strength value specified in BS 4994: 1987, which is 12.78 MPa compared to 7 MPa. Overall, laminate of tank wall has good shear strength between WR and CSM surface.

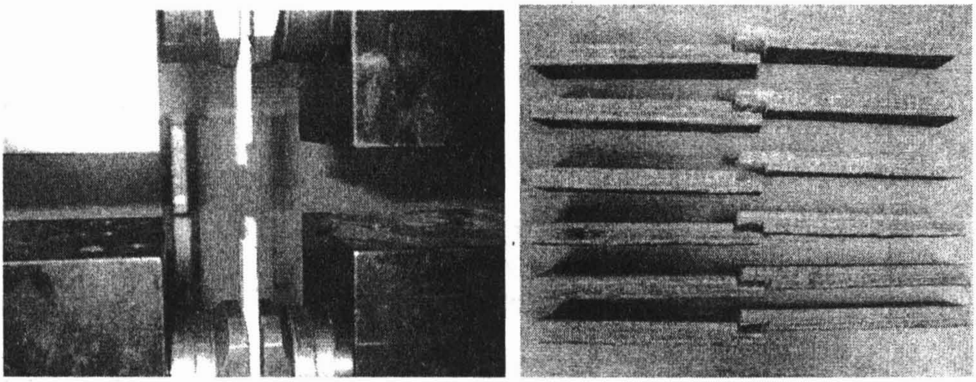


Fig.12: (a) Lap Shear Test using DARTEC, (b) Failure Specimen by Lap Shear Test

Table 3: Lap Shear Test Results

Sample	t_{avg} (mm)	w_{avg} (mm)	F_{ult} (kN)	S(MPa)
B1	8.987	25.03	21.2	14.84
B2	9.247	24.25	22.0	11.68
B3	8.33	25.23	17.7	9.38
C1	8.603	25.59	19.0	11.94
C2	8.813	23.63	20.0	15.07
C3	8.97	24.77	19.21	13.76
Average :	**12.78**			

Burn-out Test

Burn-out test was conducted by burning the wall sample in high temperature until all the polyester resin was burnt, leaving the fibre glass stiffener. From this test, several parameters can be determined, which are wall laminate lay-up sequence and stiffener weight-resin ratio.

This test was conducted according to the MS1390 testing standard (Appendix D) with sample size 200mm x 143mm. The burn-out test procedures are using burning temperature up to 600°C with duration about 30 minutes. The specimen was burnt in CARBOLITE furnace with maximum temperature of 1200°C. Figure 13 shows the test procedure and sample condition.

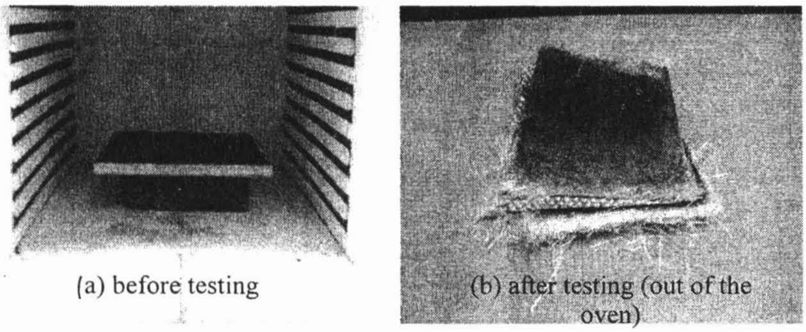


Fig.13: Burn-out Test Procedures

As a result, the wall laminate arrangement was as shown in Figure 14. From the laminate arrangements, it was discovered that there are 6 layers of CSM and 4 layers of WR, making the total of 10 laminate layers.

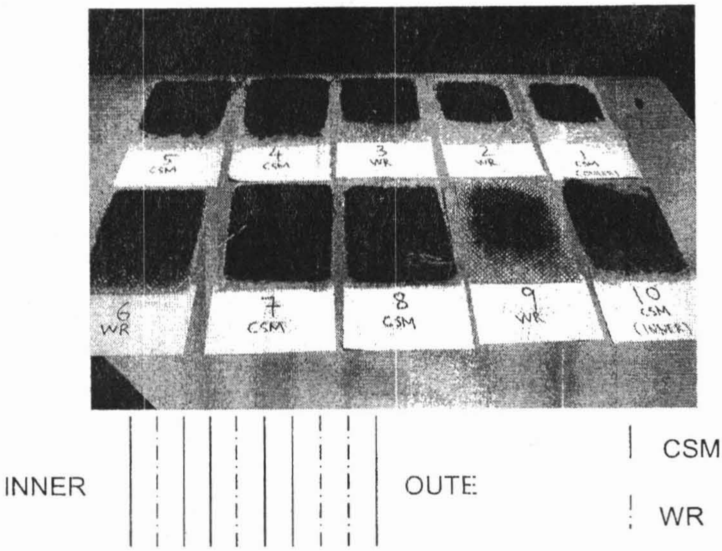


Fig. 14: Laminate Arrangements can be seen after Burn-out Test

From the burn-out test conducted, the composition of matrix and resin was identified. More over, the arrangement of woven roving (WR) and chopped strand mat (CSM) type glass fibre layers can be observed. After comparing it with original laminate arrangement from the manufacturer, the total amount of laminate are the same, which are 10 layers. However, from calculation based on BS 4994: 1981, the amount of laminate needed is 13 layers. Therefore, reducing the amount of laminate is risky as the safety factor is lower than the ideal safety design.

Discussion

The summary of the all tests are shown in Table 4. Comparisons have been and comments are also described in the table regarding to the failure of the tank.

Table 4: Comparisons and Comments from the Investigator

	Test	**Comparisons**	**Comment**
1	Tensile	SIRIM MS1390 (*min 63 MPa*)	Exceed minimum level (**94.36 MPa**)
2	Bending	SIRIM MS1390 (*min strength110MPa, modulus min 4830MPa*)	Exceed minimum level (strength = **125.23 MPa** Modulus = **6091 MPa**)
3	Shear	BS 4994 (*4-7 MPa*)	Exceed minimum level (**12.78 MPa**)
4	Burn-out	SIRIM MS1390 (*min stiffener content percentage 25%*)	Exceed minimum level (**40%** fibre content)

Then, from tank design and construction technique, there are two tanks design were considered, which was built from the manufacturer and designed from PUSKOM, UTM officers. There are differences between the designs and are shown in Table 5.

Table 5. Comparisons from the Tank built with the Designer Specifications

Item	**Manufacturer** (*Atostech*)	**Designer** (*PUSKOM UTM*)
Number of laminate (M=CSM, **R**=WR)	10 layers on the lowest wall (M/**R**/**R**/M/M/**R**/M/M/**R**/M)	13 layers on the lowest wall (M/M/**R**/M/**R**/M/**R**/M/**R**/M/**R**/ M/M)
Wall design	No stiffener	With stiffener
Flange hole	Not treated	Treated with polyester resin or poly-putty
Hole compensation	None	Necessary on the inner and outer part of the hole
Wall assembly	No extra laminate on the outer part of the wall	Necessary (at least 3 layers of CSM)

Conclusion

After investigation and examination made based on observation and testing of the tank, it is found that maybe the tank construction technique, which did not follow the original design and environmental factors maybe the cause of the failure of GFRP 13,200 gallons water tank. Tank construction process should follow all the matters in design whether in calculation or engineered drawing. Details contained in design and engineered drawing must not be ignored to avoid any problems in the future.

If any changes or problems persist at the site, technical supervisor at the workplace must refer to the consultant involved to avoid any problems. The risk for the tank to experience failure is high if the changes and decision made were not taken seriously.

Generally, based on the tensile, bending and shear tests, the strength of the materials used exceeded the minimum standard safety level. Quality of laminate on the tank wall is also good and has no problem based on the burn-out test results. Therefore, construction technique strongly affects the reliability and sturdy of a tank.

Acknowledgements

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