Design of Resin Transfer Moulds for Underwater Shells

GangadharAngadi*[1], Mithilesh K M[2], Roopa T S[1], Sridhar R[1], Salim Firdosh[3]

[1]*Department of Mechanical Engineering, RV College of Engineering, Bangalore*
[2]*Department of Mechanical Engineering, PES University, Hosur Road, Bangalore*
[3]*Department of Mechanical Engineering, RNS Institute of Technology, Bangalore*

Abstract

Resin Transfer Moulding offers advantages such as good surface finish on both sides of the part, lower void content, dimensional stability and adoptability for complex shapes.Although a number of thermoset matrices as well as industrial manufacturing equipment for resin transfer moulds are commercially available today, the design of a mould is still based on skills and personal experience of the designer. This paper presents guidelines for designing Resin Transfer Mouldsfor fabricating cylindrical underwater shells. A transversely split mould was designed and fabricated by using EN8 steel. The injection and vent ports were positioned at bottom most and top most parts of the mould respectively. Pack and Bleed mechanism was adopted to ensure mould filling. Containment seals using silicone rubber O-rings were used for resin containment without any leakage. Edge injection strategy through an edge manifold was adopted to avoid the weld lines. Experimental buckling pressure of a vinylester/glass shell fabricated by RTM was 10MPa.

Keywords:*Resin Transfer Moulding, Design guidelines, Underwater shells*

1.0 Introduction

Resin Transfer Moulding is a polymer replication technique employed for manufacturing fibre reinforced polymer composites. High production rates of intricate profiles with almost negligible voids and highfibre toresin ratio resulting in superior surface finish on both sides of the mould are the advantages of RTM technique[1, 2].It is a low pressure (less than 700 KPa) process meant for low viscosity resin and closed mould process which results in good surface finish on both sides of the part [3].Superior matrix quality and lower void content of RTM specimens lead to higher interlaminar shear strength [4, 5].Combination

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**Mail address: Gangadhar Angadi, Assistant Professor, Department of Mechanical Engineering, RV College of Engineering, Bengaluru – 59*
Email: gangadharangadi@rvce.edu.in, Ph: 8105888568

of fibre materials and their orientation including 3D reinforcements can be achieved by RTM [6].

Resin Transfer Moulding has several steps. Itbegins by shaping the dry woven preform with required shape or size before injecting the resin into the closed mould[7]. The mould is closed by screws and low viscosity catalyzed resin is pumped into the mould through theinjection ports at constant pressure to displace the air through the strategically placed vents. After curing, the near net-shape component is removed from the mould.The process comprises of two or more part matched-metal mould which has a mould cavity conforming to the shape of the desired part. A generic RTM process is presented in Fig. 1.

RTM moulding include parameters related to resin formulation, catalyst, reinforcement, part thickness, number of layers, injection port and vent port[8].These parameters influence filling and curing times. Injection pressure and temperature of the mould are important to fabricate RTM parts with good quality [9].

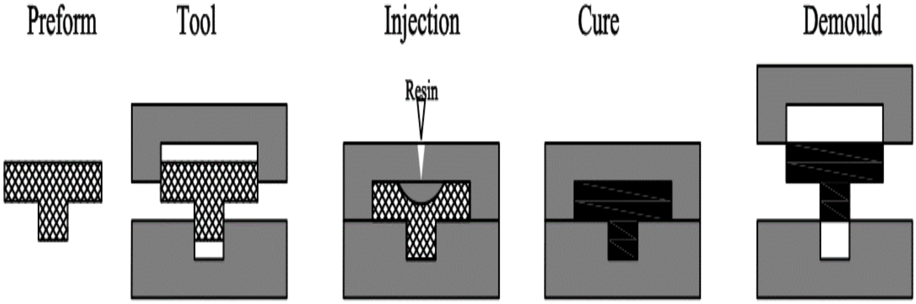


Fig. 1. Generic RTM process

RTM has unique features such as dimensional stability,ability to produce very complex parts, surface finish on both sides, lower tooling costs, amenability for automation resulting in higher production rates with less scrap, higher and consistent fibre volume fraction in comparison with open mould process. Challenges of RTM include high tooling costs for large production runs,mould filling software is still in the development stage, preform and reinforcement alignment in the mould is critical, etc. The most critical requirements are the design of matched, leak proof moulds [10]. Schematics of a typical RTM injection setup is shown in Fig.2.

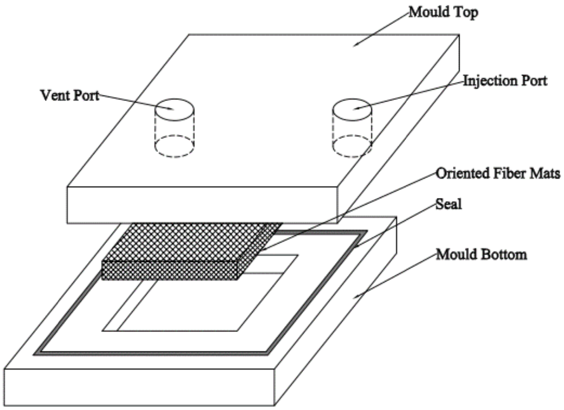


Fig. 2. Schematics of an RTM mould

RTM tooling consists of matched mould,generally made of EN8 steel, with fine surface finish. Mould material is selected based on physical, mechanical, chemical and machinability properties [11].Tooling requiresaligning the mould halves by using guide pillar and guide bush, a port/inlet to introduce resin in the closed mould, vents to let the air out, positions of injection and vent ports with flow pattern and injection pressure. Several authors developed models to determine optimum gate location and predict filling time[12-15]. The authors suggested use of seal to contain the resin in the tool and a method to clamp moulds together and demoulding. An accurate mould set alignment is to be established during the mould design stage itself [16]. RTM tools are classified as hard and soft tools. Hard tools are made of aluminium, electroformed nickel or steel moulds. Soft tools are fabricated by using polyester or epoxy.

RTM machines are custom designed for specific resin systems. This is because catalysts, accelerators, promoters or hardeners are resin dependent. Mixing of these in the required ratio is a complex problem. Generally, resin and reinforcement fibre used in RTM components are polyester, epoxy and glass. SPARTAN II RTM machinedesigned for polyester and vinylester was adopted for the present research as vinylester is a preferred resin for underwater shells because of its superior chemical resistance [17, 18].

Review of literature on the design of RTM moulds [1-18] indicated that RTM is preferred for high tech applications because of its advantages. Qualityof RTM parts depends on the design of RTM moulds which is a complex process. Comprehensive guidelines for design of RTM moulds is not available in the open literature. The main objective of this research was to evolve guidelines for design of RTM moulds considering a cylindrical shell component for underwater applications.

2.0 Materials and Resin Transfer Machine

Cylindrical shell of length 850 mm, inner dia. 175 mm and thickness 15 mm was fabricated using SPARTAN II RTM (Fig. 3 and Table 2) and the specimen was tested for hydrostatic buckling. Thickness of the shell was derived to meet working depth of 1000 m below the sea level. Vinylester and 2D woven glass fibre were used. The specifications of resin, accelerator, promoter, catalyst and glass fibres are shown in Table 1.

Table 1. Resin and Reinforcement used for RTM specimens

Materials	Specifications	Suppliers
E-Glass Fibre (360 GSM)	Density: 2.5 g/cc, UTS: 3400-3500 MPa Young's modulus:70-75GPa	SuntechFibres& Polymers, Bangalore, India
Vinylester Resin**(100g)** (Polyflex GR 200-65 superior)	Density: 1.05 g/cc UTS: 60MPa Flexural Strength: 130MPa Heat distortion temperature: 125^0C	Naptha Resins & Chemicals (P) Limited, Bangalore, India
Di-Methyl acetamide as promoter**(1ml)**	Density: 0.94 g/cc	
Cobalt napthalate as Accelerator**(1ml)**	Density: 0.98 g/cc	
Methyl Ethyl Ketoneperoxide (MEKP) as catalyst**(1.5ml)**	Density: 1.17 g/cc	

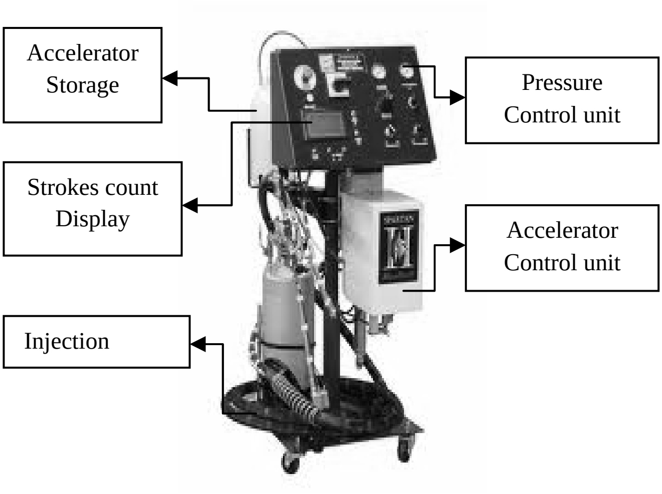


Fig. 3.SPARTAN-II RTM machine

Table 2. RTM machine specifications

Parameter	**Range**
Maximum fluid working pressure	9 MPa
Maximum air inlet pressure	0.7MPa
Maximum fluid temperature	38ºC
Resin inlet size	15/16-12 UN-2A Male
Sound pressure	84.83db
Sound power (ISO 9614-2)	87.04db
Dimensions	35mm length x 35mm width x 59mm Height (889 x 889 x 1498.6 mm)
Weight	135 kg
Wetted parts	Catalyst - Chemically coated aluminium, stainless steel, chemically resistant O-rings. Resin - Carbon steel, carbide, chemically resistant O-rings

3.0 Guidelines for Resin Transfer Mould Design

Mould design considerations are similar in injection moulding and RTM. Fig. 4 presents decision matrix as a road map for RTM mould design. Relevance of each parameter is highlighted.

Mould Unit / Parameter		Injection Moulding		RTM
		Thermoplastic	Thermoset	
Mould	Insulated Plate	□	■	■
	Gate	■	■	■
	Runner	■	□	□
	Sealing	□	□	■
	Draft Angle	■	■	■
	Air Venting	■	■	□
	Vent Port	□	□	■
	Cooling channel	■	□	□
Injection Unit	Mixing Unit	□	□	■
	Injection Pressure	■	■	■

■ Relevant   □ Not relevant

Fig. 4. Relevance of mould unit / parameters for RTM mould design

Design of moulds requires consideration of mould material and geometry, parting line, sealing of the mould, ejectors, and injection / ventilation port placement,etc(Table 3). Accurate design of mould requires study of flow characteristics of resin/matrix in the mould, which influences the properties of the finished parts such as air bubbles, voids, dry spots, fisheye, and short fill.

Table 3. Guidelines for RTM Mould Design and their adoption for the Cylindrical Mould

Part orientation and materials
• Study shape and cross section of the part • Keep larger cross section of the part on the lower side such that top risers can be placed on high points Because of uniform cross section(cylindrical shell) vertical orientation and horizontal parting line was selected.
Parting line placement
Position of runners, gates and sprue between the parting surface • Place the parting line at lowest height and largest cross section(parting plane at mid height has advantage of filling the bottom with colder material and it promotes sequential solidification) Two parting lines were selected one each at bottom and mid-height of shell.
Injection port
• Select size of the port to suit the flow rate of the material • Avoid sudden changes in the direction of material flow • Keep minimum distance from the injection port to the extreme part • Provide minimum 5% taper to avoid aspiration of air • Keep cross section of riser slightly greater than that of feed section Manual sealing injection port was placed on the part flange
Gate
• Use standard sizes and shapes for gates at thicker sections • Provide slight taper for gates towards the partto streamline the flow • Locate gate on the core side • Provide multiple gating for decreasing pouring temperatures Edge injection strategy through an edge manifold gate was selected to avoid the weld lines.
Vent port
• Provide vent ports which act as reservoir for filling the mould during solidification ensuring degasification and creating pressure heads • Place vent ports for last to solidify material • provide spherical and circular vents for high volume to area ratio • Prefer circular vents for ease of machining For shell of uniform thickness, longest straight-line path is its diameter. Hence, two vent ports were placed at the top surface of the mould.

Containment seal
• Place containment seal or gasket around the periphery of parting surface area for containing the resin under pressure Silicon rubber O-ring fitted into the groove was placed around the parting line of mould.
Draft
• Provide minimum draft angle of 1^0 on all the surfaces parallel to mould opening • Provide greater draft angle to promote better material flow, low warpage, and ease of mould release
Surface finish quality
• Ensure good surface finish of mould to achieve desired surface finish of part and for greater distance of material flow avoiding flow marks
Miscellaneous
• Treat mould properly with release agent such as wax for ease of demoulding • Close vent port manually with the help of screw to create pressure differential inside the mould to facilitate resin filling

4.0 Experimental Details

4.1 Fabrication of RTM Mould for cylindrical shell

Mould was divided into three subassemblies such as core, bottom cover and top cover(Fig. 5). Sequence of assembly involved three major steps. Initially core and flange were assembled. The flange exactly coincided with the groove provided at the bottom of the core and welded using gas welding (Fig. 5a). Plain flange was welded to the top cover of the bottom surface. The inlet port was welded to the bottom surface flange with the groove to fit the rubber O-ring into the top surface of the bottom cover (Fig.5b and 5c). All the three subassemblies were aligned so that the inlet port is on top of the manifold, top cover is aligned with the bottom cover and all the three parts are held together with M12 bolts. The procedure for shell fabrication is outlined in Table 4.

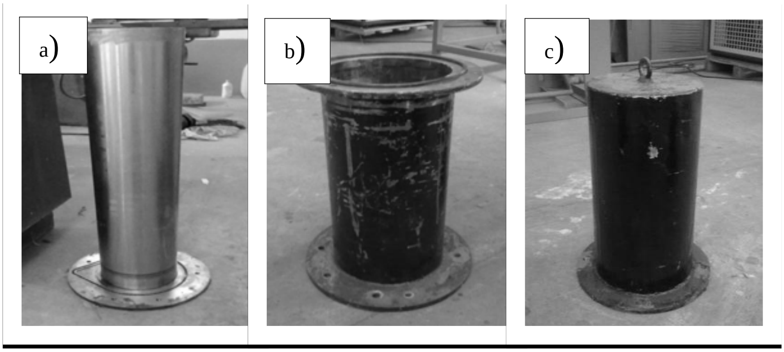


Fig. 5. (a) Core (b) Bottom cover and (c) Top cover

Table 4. Procedure for shell fabrication

Clean the surface of the mould using cleaning agents such as mineral spirit, acetoneand mineral turpentine.
Fit mould with rubber O-ring (Fig.6). Flanges are provided with groove to prevent leakage.
Apply release agent (e.g. wax) to surface of the mould.
Cover core surface with Mylar sheet (Fig.7).
Apply release agent (e.g. wax) onto Mylar sheet
Cut fibre to the required length
Wind fibre on top of Mylar sheet (Fig.8)
Align the three subassemblies with clamp (Fig.5)
Inject resin into the mould at the designed pressure and allow complete part curing.
Demould the subassembly using a fixture, visually inspect for defects
Test the shell for hydrostatic buckling.

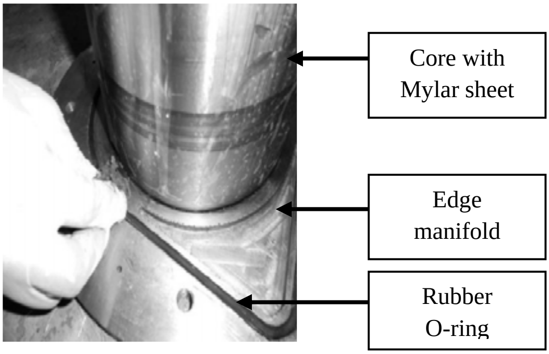


Fig. 6. Rubber O-ring fitted within the groove

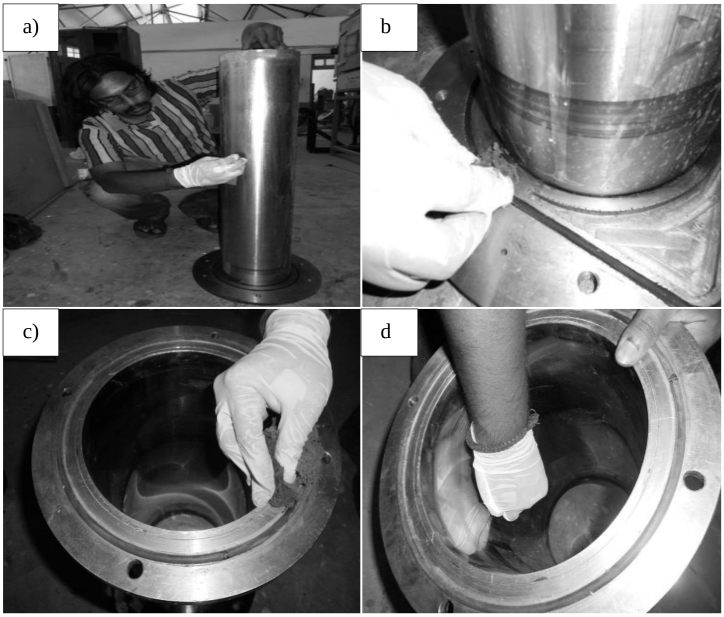


Fig. 7. Coating with release agent (a) Core with Mylar sheet, (b) Bottom flange, (c) Middle flange and (d) Inner surface of top and bottom cover

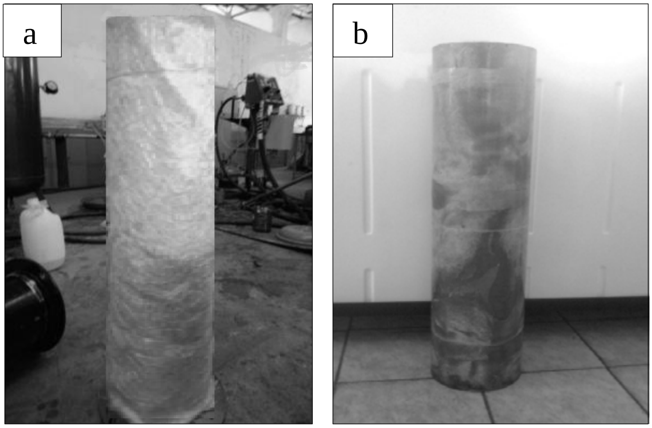


Fig.8. a) Fibre wound around the core and b) Shell fabricated by RTM

4.2 Testing of Shells for hydrostatic buckling

Before the shell was mounted on to the buckling tester, four strain gaugeswere mounted circumferentiallyat0^0, 90^0, 180^0 and 270^0 andlongitudinally at 126^0 and 162^0at the inner surface (Fig. 8). Four strain gauges were mounted circumferential direction and two strain gauges were mounted in longitudinal direction. Circumferential strains are significantly greater than longitudinal strains and hence buckling failure depends on circumferential strains. Hydrostatic pressure was applied on the shell in the buckling tester of capacity 30 MPa, which was custom designed to suit testing of shells of internal diameter 175 mm, thickness 15 mm and maximum length 1000 mm.A high pressure oil pump was used to apply hydrostatic pressure.Initially, pressure in the tank was increased in steps of 2.5 MPa till the shell showed linear strain response. Beyond the elastic range, the pressure was increased slowly in the steps of 0.5 MPa till total collapse.

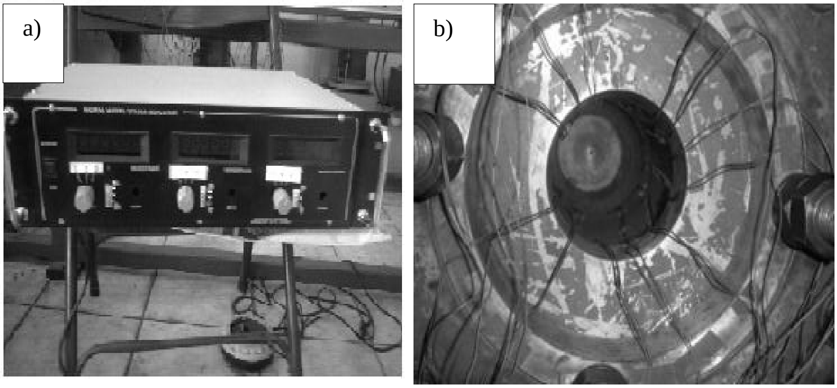


Fig. 9. a) Strain indicator and b) Buckling set up along with strain gauges mounted on the vessel

5.0 Results and Discussion

Circumferential and longitudinal microstrains are presented in Fig.10 to 12. The buckling response was elastic up to 10 MPa and the cylinder collapsed at 11 MPa. Circumferential strains in the four directions were the same in the elastic region. Significant deviations were observed above 10 MPa.The microstrains as a function of position of the strain gauge showed agreement in the elastic range(Fig. 11). Thus, it is observed that the magnitudes of the circumferential strains grew with increasing external pressure, eventually making a distinct wave pattern prior to collapse. Fig. 13 shows the buckled shell.

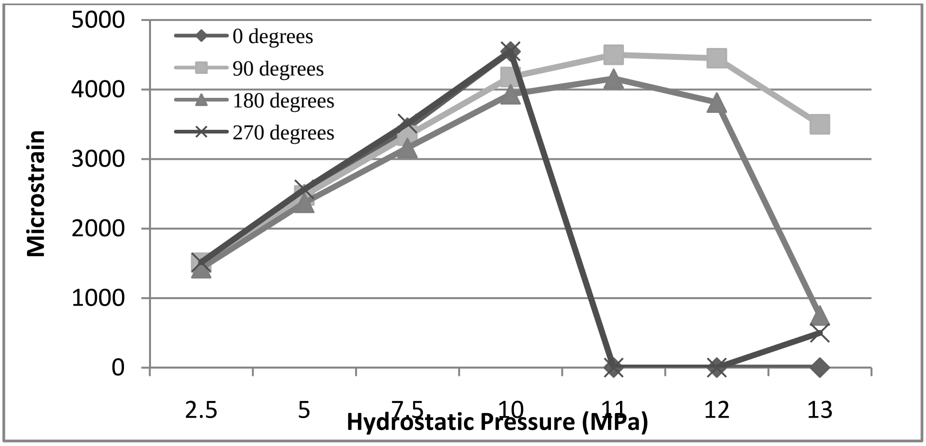


Fig. 10. Circumferential strains of 15 mm thick vessel at different locations

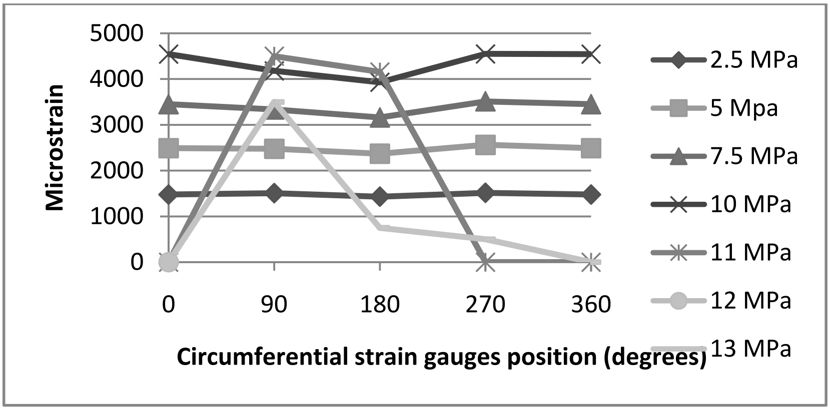


Fig. 11. Longitudinal strains for 15 mm thick vessel at various applied hydrostatic pressures

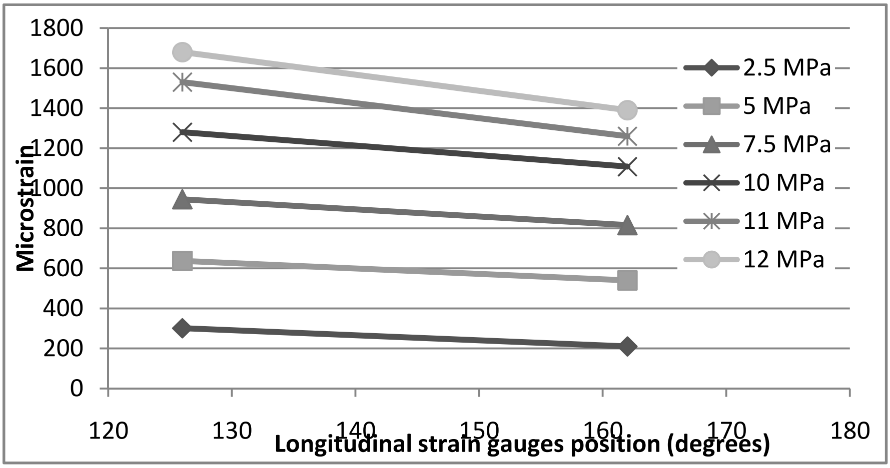
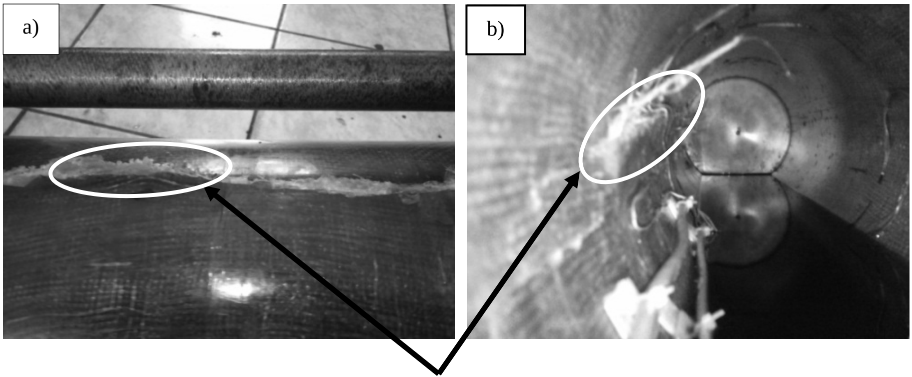


Fig. 12. Longitudinal strains for 15 mm thick vessel at various applied hydrostatic pressuresSeverely damaged part of the buckled vessel



Severely damaged part of the buckled vessel

Fig. 13. a) Outer and b) Inner Surface of the buckled vessel

6.0 Conclusions

- Based on the general guidelines for mould design, an RTM mould was designed and fabricated to realise an underwater shell of specified dimensions.
- The design experience lead to the formulation of comprehensive guidelines for the design of RTM moulds for cylindrical shells.
- The shell made of glass / vinylester was tested for buckling and the critical buckling resistance was 11 MPa.
- A fibre mat winding mechanism may be adopted to wind the mat with tension to improve the buckling performance.

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