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DESIGN AND FABRICATION OF A LABORATORIAL RESIN TRANSFER MOULDING

Bruno Moura Miranda
Wanderley Ferreira de Amorim Júnior
Francisco Neto
Federal University of Campina Grande, Av. Aprígio Veloso, 882, Bodocongó Campina Grande-PB, Brazil
bmouramiranda@gmail.com
wanderley@dem.ufcg.edu.br
francisconeto.cg@gmail.com
Diego David Silva Diniz
Federal Rural University of Semi-arid, RN 233, KM 01, Caraúbas-RN, Brazil
diego.diniz@ufersa.edu.br

Abstract. *The objective of this work was design a laboratorial Resin Transfer Moulding Equipment to process composites. The following methodology was fulfilled: Design and manufacture of the equipment, testing its process capabilities, injection tests in the processing stations, manufacturing of composite plates and further characterization. The materials used in the experiments were glass fiber mat (450g / m2), base glass fiber fabric (600 g / m2), a medium viscosity 1.0 Arazyn Ara Ashland ® # 08 unsaturated polyester resin and 50 Butanox. Small and large area plates were produced with dimensions of: 175x125x5mm and 340x340x5mm respectively. Based on the results experiments, it is concluded that it was possible the design, development and manufacture of a resin injection equipment RTM for laboratory use with low cost and low energy losses, for the manufacture of composites with two reinforcement kind: mat and fabric, with different weights and thin.*

Keywords: *Resin Transfer Moulding; Composite Plates; Processing Station; Small Area Plates; Large Area Plates*

1. INTRODUCTION

In recent decades, composite materials have gained prominence on the world scenery and with plastic and ceramic, is the material who has the fastest growth in production volume and penetration of new markets (Barbero, 1999).

Thus, the composites have great industrial importance because of its specific characteristics and properties. Within this aspect, such materials allow the engineer to some extent, designing material emphasizing the necessary features and minimizing other undesirable, adapting them to each application (Mendonça, 2005). A range of properties is relevant and can be manipulated, such as low weight, stiffness, static resistance, abrasion and corrosive environments, insulation or electrical conductivity, thermal and acoustic (Soeira, 2009).

In general, the composite is present in two phases: the continuous phase and the dispersed phase, also called matrix and reinforcement, thus the main function of reinforcing the matrix is involved. In the case of fiber-reinforced composites, the matrix serves to bind the fibers to each other and to promote the transmission and distribution of the stresses when the material is subjected to applied loads (Potter, 1997). The increase is directly responsible for the mechanical properties such as tensile strength, hardness, toughness and stiffness.

Amorim (2007) explains that for processing of composite parts, the known prior generation of designs for minimum weight, shifted its focus to the awakening of the various industrial sectors in the 80s and 90s reaching generation projects for minimal cost (design for cost): Traditional processes such as manual lamination (hand lay-up), projection by rolling (spray-up) and filament winding (filament winding). These processes can be considered with low productivity and relatively simple geometries specific to the detriment of the autoclaving processing which uses pre-impregnated (known as pre-pregs). This is adopted to the production of high performance composites. No need for an inert gas during its process combined with a pre-pregs storage under refrigeration. The inherent complexity of the process leads to increased cost. Therefore, the possibility of producing composite parts using a technique that have a adequacy between a good quality at a low cost has made the RTM method, obtain great interest and development took place in the most varied production fronts, suffering variations and generating a new range of methods, of which the RTM and Light Vacuum assisted RTM (VARTM) serve as an example.

In this respect, the process of resin transfer molding (RTM) has been increasing substantially due to the quality of finish of the final product as well as its high capacity and low environmental impact.

This processing by RTM was originally developed for aerospace applications general in the 1980s and its development was supported by a substantial research effort aimed explain fundamental aspects of the same by means of effective models (Potter, 1999).

As (Amico and Lekakou, 2001) resin transfer molding has been studied extensively over the past decade and its advantages are well established, and is considered a versatile process capable of producing composites with different shapes and major structural performance. Based on (Sheard; Mantell, 1998) the RTM allows a wide range of preforms materials and this flexibility allows the part design, ranging from small to large, structural performance tailored for a particular application.

By this process, the fibrous reinforcement is generally dry and often mounted out of the mold as a preform, with geometrical characteristics of the final product (Morren et al, 2008). After, the preform is placed in the mold and then the same is closed. There then injecting a resin solution and the catalyst impregnated fiber and the mold completely initiate the curing process, culminating in the production, post-curing of the finished composite (Ferland et al, 1996).

Amorim (2007) notes that factors such as the process allows various architectures to mold large parts, using a variety of resins and high fiber volume fraction. Enabling then, various types of surface finishes, with good dimensional tolerance with low cost of equipment to manufacturing (molding and injection system), proving that processing by RTM is one of the most promising manufacturing techniques of composite materials and is already being widely used (Goss, 2010). Further expanding the advantages presented by the process, the viability of the designer to develop materials for specific applications, to design the composite material with predetermined properties to meet local and specific conditions loading.

The objective of this research was to design a resin injection equipment for RTM, laboratory nature and cost through a design methodology, able to process effectively composite plates with polyester matrix and reinforcement fiber of glass.

2. MATERIALS AND METHODS

This work was carried out in the *Laboratório de Projeto de Instrumentos* - LPI and *Laboratório de Materiais e Estruturas Ativas* - LAMMEA, with the support of *Laboratório de Máquinas Hidráulicas e Pneumáticas* - LMHP in the mechanical engineering department of UFCG.

For this work, the methodology is divided into three distinct phases, presented as: design and manufacture of the resin injection machine by RTM; process, manufacture and dimensional and visual assessment of composite plates processed by this equipment and testing of mechanical properties of these produced plates by a tensile test.

2.1 Design and fabrication of a RTM resin injection equipment

A Design of equipment is a specialized process of problem solving. In this paper, a methodology was used with a number of main stages in a chronological sequence. In Fig.1, you can observe the flowchart of the methodology employed projects, as well as an explanation of its main stage.

- Stage 1 - Informational Design (Problem Definition): it is the interpretation and the limitation of available requirements clearly and objectively. This time, met a framework of possibly necessary information for the development of equipment. Thus, there was extensive research in finding information related to device design requirements to be developed;
- Stage 2 - Conceptual Design: aims to be represented in the best possible way, in the form of sketches, diagrams and blueprints to the idea view that best meets the demands of the project established in the informational project;
- Stage 3 - Preliminary Design: looking up through calculations and numerical simulations to establish materials, thicknesses and configurations that best resist the requested efforts and project specifications accordingly;
- Stage 4 - Detailed Design: manufacturing processes are established according to the rules prevailing in the country, when operational safety and reliability of the product, thereby detailing its documentation for future construction thereof;
- Stage 5 - Manufacture: They use up the available resources for manufacturing and assembly, with respect to obtaining the physical form established in previous phases of the project;
- Stage 6 - Validation Test: tests are performed to check the service prototype design specifications, therefore, the initial demand.

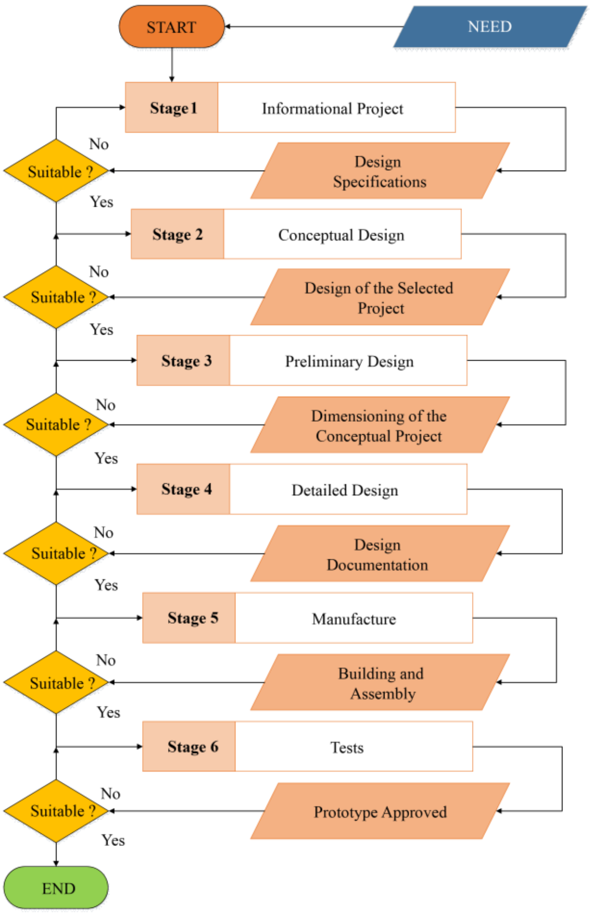
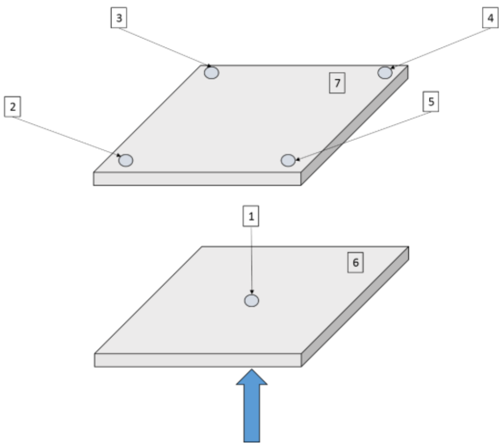


Figure 1. Adopted project methodology flowchart.

In the four first stages, it was aided by Autodesk Inventor 2013 software - Educational version, for which he was allowed modeling and finite element simulations to stress the components analysis. All design and manufacturing steps are described in detail at (Miranda 2015).

2.2 Process, manufacturing and visual evaluation of composite plates

After finishing the phases relating to the design and manufacture of the RTM injection equipment, the manufacturing step of the small area boards and large area plates was initiated to a thickness of 5mm. All injections were performed with the following settings: Injection in the central point of the bottom plate of the mold and air vents on all four sides of the upper plate (fig. 2). A variation in process parameters shown in Table 1, to determine the best conditions for manufacturing the plates.



1 – Injection point;
2, 3, 4, 5 – Air vents;
6 – Bottom plate;
7 – Upper plate.

Figure 2. Inlet and outlet configurations.

Test	Plate dimensions (mm)	Preform		Pressure at AH (Bar)	Resin Volume (ml)	Catalyst Percentage (%)
		Reinforcement type	Number of layers			
1	175x125x5mm	Mat	3	3	600ml	3%
2	175x125x5mm	Mat	3	4	600ml	3%
3	340x340x5mm	Mat	4	3	1000ml	3%
5	340x340x5mm	Fabric	4	4	1000ml	1%
6	340x340x5mm	Fabric	6	5	2000ml	0,5%
7	340x340x5mm	Fabric	7	6	2000ml	0,5%
8	340x340x5mm	Fabric	7	6	2000ml	0,5%

Table 1 – Tests parameters

The materials used for the processing of the composite plates were:

- Unsaturated orthophthalic polyester resin with medium viscosity Arazyn 1.0 # 08 Ara Ashland ®;
- Reforço: E-Glass fiber mat from OCV Capivari Fibras de Vidro Ltda, with 450 g/m^2 grammage and basic E-glass fabric, with 600 g/m^2 grammage provided by Redelease ®;
- Methyl ethyl ketone peroxide catalyst (P-MEK), BUTANOX M-50 Akzo Nobel;
- Release agent: Polyvinyl alcohol (PVA) provided by pela Redelease ® and *carnaúba* wax Tecglaze ®.

2.3 Analysis of mechanical properties of processed plates

The mechanical properties of the plates were evaluated by tensile testing, following the recommendations of ASTM D3039/D3039-14 showing a method of obtaining mechanical properties of polymer matrix composites. The dimensions of the specimen was in accordance with the orientation of the fiber and a rectangular shape with dimensions of width, length and average thickness respectively of 25 mm x 250 mm x 5,7mm.

1 – Testing Machine MTS ®;
2 – Load Cell
3 – Tension test assembly
4 – Specimen before the test
5 – Specimen after the test

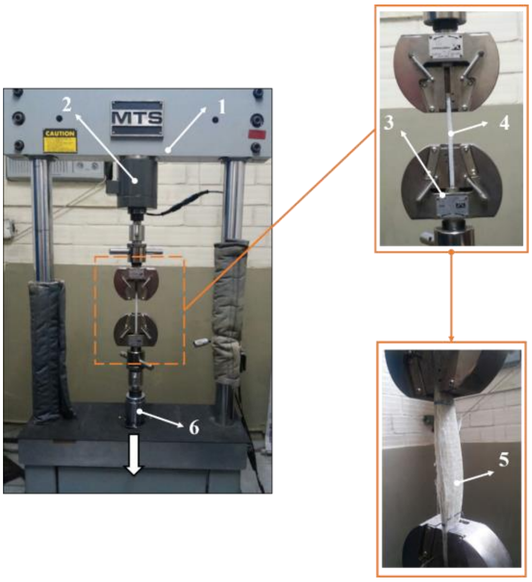


Figure 3. Tension test assembly.

The test was conducted on a universal testing machine MTS hydraulic servo ® 810 (Fig. 3), load cell 100 kN, at a 2mm / s displacement rate with no preload. They were measured, again according to the standard used, the maximum tensile stress ($\sigma_{máx}$) and the rupture deformation in percentage (ε_{rup}).

3. DISCUSSION

3.1 Developed equipment characteristics

Miranda (2015) developed two concepts. The laboratorial concept was approved and manufactured. This concept presents the simplest solutions to the structure compared to the researched equipments. Four wheels, a table and a “U” component support the entire structure. This component led to the reduction of various components as well as substantial reduction in project costs. This design is intended to refer to 25% of the pressure ranges Miranda (2015) equipment and resin injection processing by RTM searched.

In Table 2 shows the technical characteristics of the design. Figure 4a and 4b An outline designed in CAD software environment for Autodesk Inventor 2013 student version to design adopted and approved, which can be seen in Figure 4c.

Laboratorial Conception		
Characteristics	**Unit**	**Values**
Pressure range	bar	1 – 3
Structural components	m.u	6
Total mass calculated by the software	kg	62,67

Table 2 – Concept Characteristics.

Figure 4 – Concept.

Comparing the two developed conceptions, the selected and fabricated presented: from 87.59% weight reduction of the structural components 73.91%, as a percentage, and pressure range. Providing then an overall cost reduction.

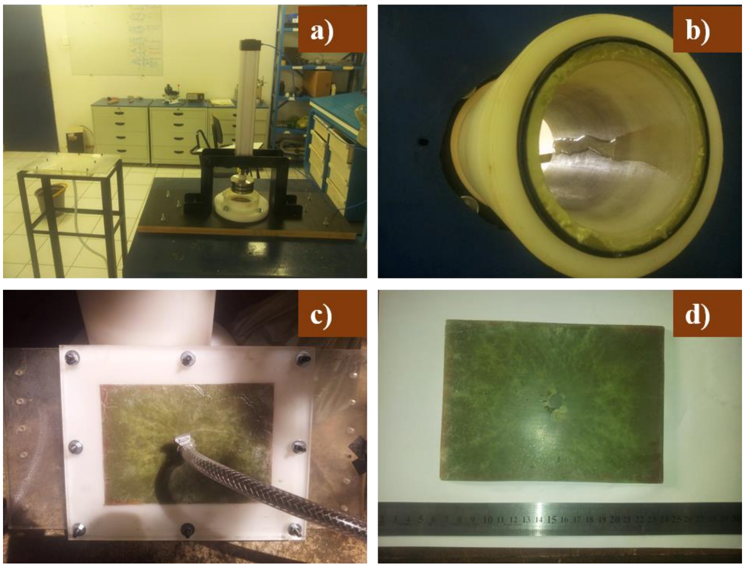
3.2. Plates injection tests

Several tests were performed to obtain prototype boards, as mentioned methodology. They present only the successful results for the plates small and large area. Further details of the tests can be found in Miranda (2015).

3.2.1. Small area plates

The first attempt injection was carried out in the laboratory of hydraulic and pneumatic machines in the mechanical engineering department of UFCG. For this was used unsaturated polyester resin, catalyst and Mekol®

laminating blanket, with the blanket being of weight 450g / m² and catalyst in a percentage of 3% relative to volume of resin. The pressure in the UTA was set at 3 bar. In the first attempt the plate was successfully obtained, showing that the machine is capable of injecting the polyester resin in a closed mold, thus validating the same. Still it was validated for such equipment, fine processing composite plates with dimensions of 175x125x5mm. See Fig. 5.



a) Assembly;
b) Sealing efficiency demonstration;
c) The spacer plate;
d) Top view of the obtained plate.

Figure 1 – Small area plate.

The average dimensional values, weight and density of the plate are shown in Table 10 below. For each dimension of value were taken three measures thus the values presented are the mean between them.

Small Area Plate		
Dimension (mm)	length	174,84
	width	125,00
	thickness	4,89
Mass (g)	-------	153,32
Density (g/cm³)	-------	1,4346

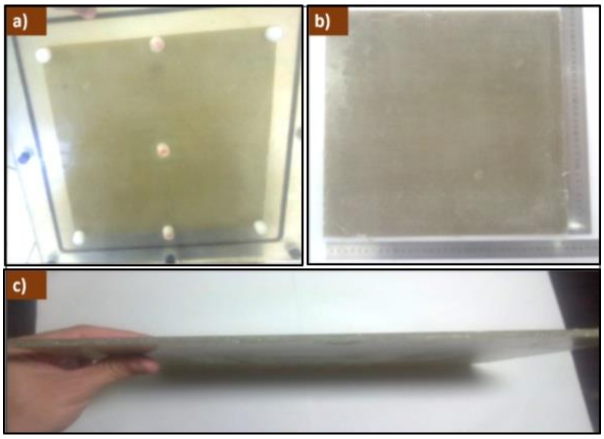
Table 3 - Design, weight and density of processed plate.

It is perceived consistency with the values obtained by Cavalcanti (2014), with discrepancies between values and the reference lower than 5%, thus demonstrating the successful processing of such boards of this size.

3.2.2. Great area plates

In the fourth injection pattern was used a preform with 7 layers of fabric with a weight of 600g/m^2, the ALU pressure 6bar, 2 liters of resin and 0.5%. For the reduction of the piston speed, it used a regulator valve Belair® unidirectional flow of pneumatic 5/2 way valve and the pneumatic cylinder.

Figure 6 presents the injection conditions and results.



a) Assembly;
b) Front view of the obtained plate;
c) side View of the obtained plate.

Figure 6 – Great are Plate.

The third test with the processing station developed for large processing areas plates succeeded in processing a plate. There was complete filling of the preform (Fig. 6a) in the figures 6b and 6c has the front and side view of the plate after extraction. This was the first plate area, validating the process described and the second successfully produced plate in the project.

The average dimensional values, weight and density of the plate are shown in Table 11 below. For each dimension of value were taken three measures are presented, then average values.

Great Area Plate		
Dimension (mm)	Length	340,00
	Width	340,00
	Thickness	5,70
Mass (g)	-------	1090,00
Density (g/cm³)	-------	1,6542

Table 4 - Design, weight and density of processed plate.

3.3. Mechanical characterization

3.3.1. Tensile test

The tensile test of the six specimens of processor board with two-way woven glass fiber type and is given in accordance with ASTM D3039 / D3039-14.

In figure 96 is presented the results to the specimen of the tensile test 06. The other graphics for the tensile test follow this trend and can be found in Miranda (2015).

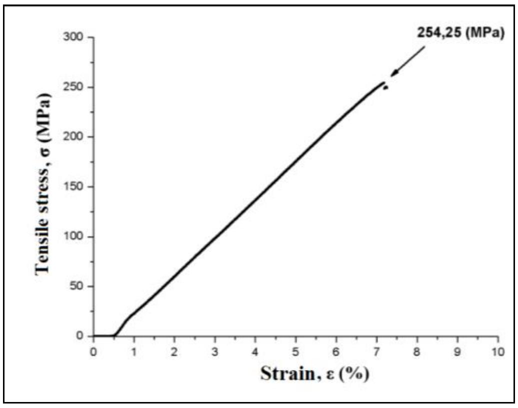


Figura 7 – tensile stress (MPa) x Strain (%) Specimen 06.

It is noted initially a slip or what we might call a room for a preload not be used, then the tension begins to rise from strain values above 0.5%. Table 21 presents the average results for the maximum tensile stress ($\sigma_{máx}$), the rupture deformation in percentage (ε_{rup}) and their deviations around averages.

Mechanical properties	Medium values	Standard deviation
Maximum Stress (MPa)	238,59	± 17,69
Rupture deformation (%)	6,71	± 0,44

Table 5 - Mechanical properties in the Medium Obtained Tensile test

It is important to note that the deviations around the mean in absolute values are low: around 7,41% to $\sigma_{máx}$ and 6,56% to ε_{rup}.

Figure 97 shows a macroscopic analysis of the damage suffered by one of the specimens imposed on the tensile test after their final break.

Figure 8 - Fracture of Composite Testing body: a) During the test b) After the test

As this standard practiced this test, the fracture occurred is the XGM type, acronym which means that the fracture was like, explosive, the useful length of the area and in the middle of the specimen.

4. CONCLUSIONS

With the second concept, it was possible to reduce the number of structural components and a reduction in weight of the order of 73.91 and 87.59% compared to the first concept, respectively.

It was successfully developed (design and manufacturing) one processing station for laboratory use Resin Transfer Molding for composite materials own design.

It was possible, with the RTM equipment designed and manufactured in this paper making composite plates with preform small area of blanket (21875mm^2) and composite plates with preform 7 layers of fabric with large area (115600mm^2) and thickness of 5 and 6 mm.

The results of tensile tests showed homogeneity on the processed plate.

5. REFERENCES

Amico, S.; Lekakou. 2001. “An experimental study of the permeability and capillary pressure in resin-transfer moulding”. *Composites Science and Technology*, Vol 61, pp. 1945 – 1959.

Amorim Júnior, W. F. 2007. *Processamento de placa espessa de compósito através de Moldagem por Transferência de Resina.* Ph.D. thesis, Universidade Federal do Rio de Janeiro, Rio de Janeiro.

Barbero, E. J. 1999. *Introduction to composite materials design.* Taylor&Francis, New York, 1st edition.

Cavalcanti, A. M. S. 2014. *Desenvolvimento da Capacitação do Processamento de Compósitos por Moldagem de Transferência de Resina.* Master thesis, Universidade Federal de Campina Grande, Campina Grande.

Goss, T. M. 2014. *Panorama e perspectivas da indústria brasileira de compósitos.* End of Course Work, Universidade Federal do Rio Grande do Sul, Porto Alegre.

Mendonça, P. DE T. R. 2005. *Materiais compostos e estruturas-sanduíche: projeto e análise.* Manole, São Paulo, 1st edition.

Miranda, B. M. 2015. *Desenvolvimento de um equipamento de moldagem por transferência de resina para uso laboratorial.* Master thesis, Universidade Federal de Campina Grande, Campina Grande.

Morren, G.; Bossuyt, S.; Sol, H.. 2008. 2D permeability tensor identification of fibrous reinforcements for RTM using an inverse method. *Composites Part A: Applied Science and Manufacturing*, Vol 39, pp. 1530 – 1536.

Potter, K. 1997. *Resin Transfering Molding*. Chapman & Hall, London.

Potter, K.D. 1999. “The early history of the resin transfer moulding process for aerospace Applications”. *Composites Part A: Applied Science and Manufacturing*, Vol. 30, p.619 – 621.

Soeira, L. E. 2009. *Projeto e elaboração de um dispositivo para remodelagem de fibras como subsistema do processo de enrolamento filamentar.* Master thesis, Universidade de São Paulo, São Paulo.

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