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THEORETICAL AND EXPERIMENTAL RESEARCH ON THE MANUFACTURE OF COMPOSITE STRUCTURES USING RTM PROCESS

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Abstract: *This paper aims to highlight the technological features of manufacture of composite structures by the Resin Transfer Molding process. Polyester resin was injected in a closed mould which had fiber reinforcements disposed there previously. . Measurements were made of tensile resistance for composite parts in an effort to influence the process parameters on these values.*
Keywords: *Composite materials, injection resins, fiberglass.*

1. INTRODUCTION

Resin Transfer Molding (RTM) process is a low-pressure injection of a resin mixed with a catalyst in a closed mold containing a reinforcing material in the form of fibers, usually glass fibers.

You can use a wide range of resins such as polyester, epoxy, phenol, combined with other pigments or fillers such as calcium carbonate if necessary.

Reinforcement material can be fiberglass, carbon, aramid, or a combination thereof.
The process begins by filling the mold cavity with the reinforcing material after the mold is closed and locked, in the mold can be created a vacuum, then the two components, resin and catalyst are pumped simultaneously by mold, they will meet at the mixing head where they will be mixed and then injected into the mold as a single component.

After the resin solidifies the mold is opened and the track removed. The vacuum pump is used to facilitate the total impregnation of glass fiber.

Polymerization reaction of the matrix can take place both at the ambient temperature and at a higher one (60-80^0) in a microwave oven called.

The principle scheme of an installation of RTM is presented in figure 1.

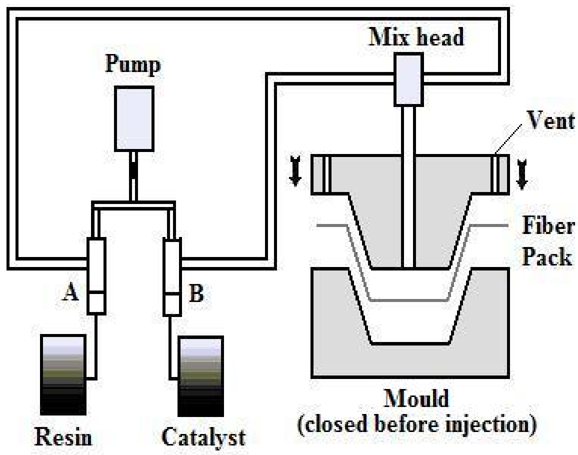

Fig. 1 The principle scheme of an installation of RTM.

2. EXPERIMENTAL INSTALLATION

To study the technological characteristics of RTM process we achieved an experimental facility that allows small-scale reproduction of the specific working conditions of formation of composite parts by resin transfer molds.

Of the many existing variants in the process of resin transfer molding we analyzed the various options in terms of functional characteristics but also through the purpose and usefulness of the solution.

Since the process is quite understudied in our country, we preferred to choose the classic solution of resin transfer, namely low-pressure injection at a low speed and to use preformed reinforcement structure.

This option is justified by the fact that we have studied the process in laboratory conditions and not to make a series production, although the research results can be used for industrial purposes. I also preferred the solution of activated resin through dosing, blending and mechanical mixing of the components in order to ensure the good quality and a uniform structure of the resin injected.

For this purpose, taking into account the way of the dosage of the constituents, I opted for a system of mixing and transfer of the resin by using the under pressure tank.

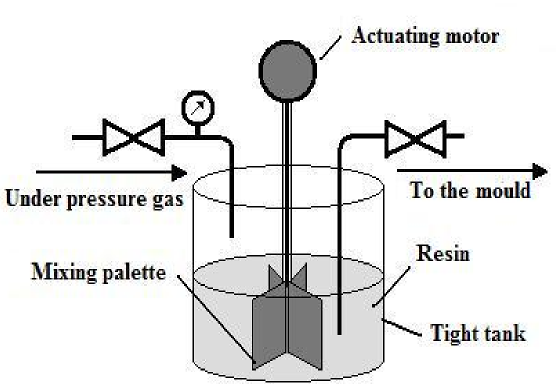

Fig. 2 Under pressure tank

In this variant using a container (tank) resin that can be tightly closed, the fluid surface is made adjustable pressure gas (air). Under the effect of pressure, the flask will be pushed through a pipe submerged in the crease on the resin mass, so it is sent to the mold cavities. It uses compressed air at a pressure of 2-6 bar adjustable.

He designed a mold for making metal parts made of composite material plate, as in these boards will be cut specimens to be tested mechanically. Between the two metal plates forming the mold is a metal frame, frame whose thickness is equal to the thickness of composite plate to be obtained by RTM process.

In Figure 3 are presented the two metal plates that form the mold.

a) b)

Fig.3 Mold
a) lower plate b) upper plate

The installation used for experimental work is composed of pressure tanks, the mold for a piece of plate, respectively the transformer that powers the compressor and mixing system.

For a faster service tank, I installed most components of the plant on the closure lid; the lid fixing screws are made to dump that allow rapid disassembly.

As can be observed from the figure, the resin with all activation constituents priory dosed by weighing, are introduced in the vessel particularly installed inside the pressure tank. After introducing the resin, the container cap is tightly closed using fasteners. So, for mixing resin is used a wide shaft driven by an electric motor.

Figure 4 shows the laboratory facility where researches were conducted.

Fig.4 Resin Transfer Moulding plant
1 - Mold, 2 - pressure tank, 3 - electric motor for mixing resin, 4 - 24V transformer, 5 - compressor.

3. EXPERIMENTAL RESEARCH

3.1 RTM process stages

Formation by RTM process stages are shown schematically in figure 5.

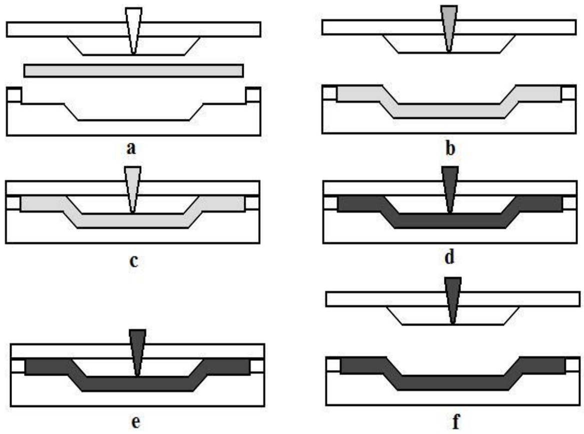

Fig.5. The steps of forming parts by RTM process. a) cutting reinforcement, b) pre-forming reinforcement, c) installing preformed reinforcement, closing and heating the mould; d) resin injection and mould filling e) achieve polymerization cycle in matrix, f) opening the mould and extracting the piece (demulation).

3.2 Establishing the quantity of resin

Further on the modality of calculation will be presented for plate P1.

In determining the amount of resin is required to charge the reinforcing material and to calculate its mass as follows:

a) the reinforcement material is fed at rates of 21.5 cm x 22.5 cm, the material used is balanced fabric (equal warp weft), 320 g/m2.

b) the reinforcement material is weighed to calculate the amount of resin required, we established the use of the set of five layers of reinforcement material to obtain a certain degree of reinforcement, the designer normally shows his technical ability in selecting the matrix and reinforcement material so that the piece of composite material can be used optimally in certain operational conditions.

$m_f=m_1+m_2+m_1+m_3+m_4+m_5=$
$=16+14+15+16+16=77$ g (1)

Fiber volume will be:

$$v_f=\frac{m_f}{\rho_f}=\frac{77}{2,6}=29,61\,\text{cm}^3 \quad (2)$$

ρ_f= fibrer density
ρ_f=2,6 [g /cm³] [6]

We will use AROPOL polyester resin type FS 799 having a density of ρ=1200 kg/m^3 , respectively 1,2 g/cm^3.

For the mold we have $V_{reș}=v_{tot}-v_{țes}$, where the total volume is calculated by the shape and size of the plate. Thus we have:

v_c= 21,5 x 22,5 x 0,2 =96,75 cm^3 (3)

- the volume occupied by the reinforcement material is cm^3.

-the volume of the resin matrix is :

$$v_m=v_{p1}-v_f=96,75-29,61=67,14\,\text{cm}^3 \quad (4)$$

The total volume of resin will take into account the losses from:
- the pressure tank ≈120 cm^3;
- the supply hoses ≈100 cm^3 ;
- the tubing of the pressure tank ≈20cm^3.

3.3 Preparation of experimental plant

- open the mold and polish the surfaces with sandpaper with 200 to 600 grit and then use polishing paste to get a proper roughness;
- apply a demulant 'formula Five', with a cloth, a very thin layer which is left to dry for 15 minutes, then polish. The operation is repeated several times (3-5 times);
- insert reinforcing structure made of glass fiber type mat and balanced fabric then the matrix closes tightly;
- determine the required amount of resin;
- dose by weighing all the matrix constituents;
- place the mixture in the tank inside the pressure vessel;
- the container lid is closed and the electric motor starts mixing the constituents;
- the gateway opens to the compressed air towards the pressure tank;
- it is ensured the transfer of resin from the reservoir to the mold cavity, waiting for the moment when it is full, which can be noticed by exiting of the resin from the mold at the outlet of the air;
- close the outlet of the resin through filling the hose;
- continue the compressed air supply of the matrix;
- stop the transfer of resin to the mold by stopping the compressed air alimentation;
- open the lid of the pressure tank and wash all the components with solvents to remove all traces of resin;

- after passing the time of polymerization (approx. 24 hours) of the composite material piece the mold is opened and the formed piece is extracted.

Fig. 6 Preparing the mold and resin transfer

For this experiment, three “board” pieces were made with the following features:

Piece No. 1 (P1), was obtained by central injection, the reinforcement material used is glass fiber type balanced fabric (equal warp weft);

Piece No. 2 (P2) was obtained by lateral injection, the reinforcement material used was glass fiber type ‘combimat’ (fabric + stratimat)

Piece No. 3 (P3), was obtained by central injection, and the same reinforcement material was used, respectively “combimat”

The calculation of mass and volume degree of reinforcement

Notations :

M_m - the percentage of the mass matrix
M_f - weight percentage of fiber
V_m - volume percentage of matrix
V_f - volume percentage of fibers
v_f - fiber volume
v_c - composite volume
v_m - matrix volume
m_c - composite weight
m_m - matrix weight
m_f - fiber weight

After the polymerization process and cutting the edges of piece we have:
$m_c = 181$ g, $m_f = 63.62$ g

$$m_m = m_c - m_f = 181 - 63.62 = 117.4 \text{ g} \quad (5)$$

Percentage of fibers mass M_f

$$M_f = \frac{m_f}{m_c} \times 100 = \frac{63{,}62}{181} \times 100 = 35\% \quad (6)$$

Percentage of matrix mass M_m

$$M_m = \frac{m_m}{m_c} \times 100 = \frac{117{,}4}{181} \times 100 = 65\% \quad (7)$$

Percentage of fiber volume V_f

$$V_f = \frac{v_f}{v_c} \times 100 = \frac{29{,}61}{96{,}75} \times 100 = 30\% \quad (8)$$

The percentage volume of the matrix V_m

$$V_m = \frac{v_m}{v_c} \times 100 = \frac{67{,}14}{96{,}75} \times 100 = 69\% \quad (9)$$

Composite density ρ_c

$$\rho_c = \rho_f \times V_f + \rho_m \times V_m \quad \text{where} \quad (10)$$

ρ_c= composite density
ρ_f= fibrer density
ρ_f=2.6 [g /cm³] [6]
ρ_m = matrix density
ρ_m =1,2 [g /cm³] [6]

$$\rho_c = 2.6 \times 0{,}30 + 1{,}2 \times 0{,}69 = 1{,}6 \text{ [g /cm³]} \quad (11)$$

Coefficient of elasticity E

$$E = E_f \times V_f + E_m \times V_m \quad \text{where}$$

(12)

E_f= coefficient of elasticity for the reinforcement material
E_f=73000 [MPa] [6]
E_m= coefficient of elasticity for matrix
E_m=3000 [MPa] [6]

$$E_l = 73000 \times 0{,}3 + 3000 \times 0{,}69 = 23970 \text{ [MPa]} \quad (13)$$

Poisson’s number ν

$$\nu_{l,t} = \nu_f \times V_f + \nu_m \times V_m \quad \text{where} \quad (14)$$

ν_f=Poisson’ number for the reinforcement material
ν_f=0,25 [6]
ν_m= Poisson’ number for matrix
ν_m= 0,4 [6]

$$\nu_{l,t} = 0{,}25 \times 0{,}3 + 0{,}4 \times 0{,}69 = 0{,}351 \quad (15)$$

3.4 The tensile test

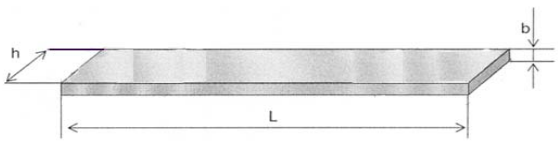

Fig.7. Specimen for the tensile test

The specimen to determine the allowable tensile strength was cut with a diamond disc to the desired size, 25 x 2 x 225 for pieces made of biaxial cloth according to ISO 527-4 [ISO97b] [8] from parts made in visualising mold (see Figure 6.).

To determine the fracture resistance (Rm) tensile ultimate strength where rupture occurred was divided by the required cross-section, for example:

$$R_m = \frac{F_{\max}}{A} = \frac{F_{\max}}{bxh} = \frac{15000}{25x42} = 150 \left[\frac{N}{mm^2}\right] \quad (16)$$

For the requested tensile the specimens were performed with parts made both through side injection and central injection. Attempts have been made on the universal testing machine type ROEL KORTHAUS located in the Research Laboratory for Manufacturing Pieces of Competitive Materials of the Technical University of Cluj-Napoca.

Fig.8 Tensile test machine

The machine is equipped with a control system with the ability to draw diagrams of variation of strength during application and elongation. Further on, based on measurements and reading the measurement of the breaking force on the face of the machine we will proceed to calculate the geometrical area and its resistance to breakage.

Fig.9 Samples tested

3.5 Experimental results

We calculate the cross-section for each of the samples. We cut six pieces, two for each piece, the first plate P_{1A}, P_{2A}, the second plate, $P_{2A,}P_{2B}$, and the last plate, $P_{3B,}P_{3B}$. The results will go in a table such as:

Tab.1 The mechanical characteristics of a composite plate

Nr.crt	Samples code	Reinforcement degree [%]	Material density [g/cm³]	Modulus of elasticity E [Mpa]	Poisson's ratio [υ]
1	P_{1A}	42	1,6	24960	0,35
2	P_{1B}	42	1,6	24960	0,35
3	P_{2A}	56	1,8	34760	0,33
4	P_{2B}	56	1,8	34760	0,33
5	P_{3A}	57	2,02	45960	0,30
6	P_{3B}	57	2,02	45960	0,30

Tab. 2 Tensile test results

Nr. crt	Sample cod	Dimensions of the samples		Section samples [mm²]	Maximum Elongations [mm]	Maximum Force [KN]	Tensile strength [daN/mm²]
		h [mm]	b [mm]				
1	P_{1A}	26,8	2,6	69,68	6,70	13,5	19,37
2	P_{1B}	25,7	2,6	67,08	6,08	10,25	15,33
3	P_{2A}	23.13	2,5	57,82	7,94	13,00	21,61
4	P_{2B}	26,86	2,45	65,80	6,55	9,75	14,51
5	P_{3A}	24,43	2,45	59,85	8,04	13,00	21,72
6	P_{3B}	26,13	2,35	61,40	8,41	15,00	24,42

4. CONCLUSIONS:

After the experimental research on composite manufacturing process using RTM we have drawn the following conclusions:

In the case of the first plate P1, made by central injection and reinforced glass fiber, type balanced fabric, although five layers were used for the reinforcement plate, the tensile resistance was lower than where we used as reinforcement material combimat fabric type, even if they used only two layers of reinforcement.

For the other two plates, P2 and P3, produced both by central and lateral injection where the same ‘combimat’ fabric type was used, there was a lower resistance in the case of central injection, this can be explained by the fact that when the resin enters the matrix and meets the reinforcement material tends to push it away, thus there can appear parts of the piece hub where the resistance is lower than elsewhere in the piece, especially for the parts with multiple injection points, therefore it is very important to establish the position of the injection points.

The problem of resin flow in porous media is a very complex one due to factors that accompany this process. Another problem is the resin flow front, especially for the parts with complex geometry where unimpregnated areas may occur.

About the future aims and further research we want to build an improved experimental installation and use reinforcement materials with special architectures to allow significant tehnological improvments of the RTM process and to increase the quality of composites parts.

Also we want to do research regarding some special arhitectures of the materials used in this process and to increase the reinforcement of composite structures obtained by this process.

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Cercetari experimentale privind fabricarea structurilor compozite utilizand procedeul RTM.

Abstract: Lucrarea isi propune să evidențieze particularitățile tehnologice ale fabricației structurilor compozite prin procedeul ”Resin Transfer Molding”. S-a injectat rășină poliesterică într-o matrita inchisa, după ce în prealabil în cavitatea acestora au fost introduse structurile de armare, respectiv straturi de țesătură din fibre de sticlă. S-au făcut măsurători ale rezistențelor de rupere la tracțiune, pentru piesele compozite realizate, urmărindu-se influența parametrilor tehnologici asupra acestor valori.

Cuvinte cheie: Materiale compozite, injectie de rasina, fibra de sticla.

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