The Influence of Reinforced Materials and Manufacturing Procedures on the Mechanical Characteristics of Polymeric Composite Materials

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Reinforced materials and manufacturing procedures have a significant influence on the quality, productivity and competitiveness of polymeric composite structures. The present study aims to highlight the influence of manufacturing procedures and the reinforced material on the mechanical characteristics features resulting from the process of being subjected to traction. Polymeric composite plates reinforced with glass and carbon fiber obtained through hand lay-up, hand lay-up with pressure and vaccum bag molding process.

Keywords: polyester resins, epoxy resins, fiber glass, carbon fiber, composite materials

Composite materials represent a class of engineering materials of genuine scientific and technical interest. They are not just a perfect substitute of ferrous and non-ferrous materials, but also materials that allow the solving of a huge numbers of technical issues in various industrial branches.

Certain technical problems can be hardly or sometimes impossibly to be solved by using of common materials.

At present due to their characteristics and quality (easy but resistant, superior mechanical characteristics, remarkable resistance to aggressive chemical agents, high resistance to cosmic vibrations and radiations etc.), composite materials have a large scale of implementation possibilities in a series of domains, such as: civil and industrial constructions, electrotechnics, electronics and microelectronics, rail-, road- and naval transport, military technique, aeronautical and aerospatial industry etc. The development of the plastic and composite material production represents an opportune and perfectly feasible alternative for the Romanian industry, which at its turn is in full phase of reorganization.

The technical literature [1-4, 9, 10] mainly deals with studies that only mark the mechanic behaviour of composite structures and do not focus on the factors influencing this behaviour. That is the reason the present study aims to elaborate the comparative analysis of some manufacturing procedures of composite structures along the influences they have on their mechanic characteristics [11-14]. The study focuses on technologies like hand lay-up with or without pressure, vaccum bag molding process and as reinforced materials structures of fiber glass and carbon fiber.

These are the reasons why the authors included this segment of modern and extremely dynamic engineering materials into the study, which produced significant developments regarding the usage of these materials in different fields, determined by the special requirements of the high technologies, as well as by the requirements relating to the mass productions of consumer goods, and last but not least by the ecological requirements [5].

Materials used for manufacturing of composite plates

The plates used during the experiments had been produced at the Composite Material Laboratory of the Faculty of Machine Manufacturing of the Technical University of Cluj-Napoca. Polyester resin was used as matrix for fiber glass reinforced materials and epoxy resin for carbon fiber.

The type and the characteristics of these materials are [6]:

For the hand lay-up of the plates:

1. Polyester resin type Norpol 440-M750 (USA). This resin is ortophtalic with low styrene emission, tixotropized and pre-accelerated.

II. Technical characteristics:	**b.** Physical-Mechanical characteristics:
• Brookfield viscosity: 250-350mPa.s	1. Break strength: 62 MPa
• Colour: Transparent blue	• Elongation at break: 2%
• Time for obtaining jelly with 2% peroxide of MEEC- 8-15 min	• Bending strength: 126 MPa • Impact resistance: 6.1 mJ/mm^2
• Exothermic peak :160-190^{0}C	• Distortion temperature when exposed to heat: 72^0 C
• Exothermic peak time: 15-23 min	
	• Barcol hardness: 43-44

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Table 1

No	Notation	Reinforced material type	Matrix type	Number of layers	Moulding procedure
1	P1	normal fiberglass tissue of 500 g/m^2	Polyester resin	3	Hand lay-up
2	P2	normal fiberglass tissue of 500 g/m^2	Polyester resin	3	Hand lay-up with pressure
3	P3	normal fiberglass tissue of 500 g/m^2	Polyester resin	3	Hand lay-up with pressure
4	P4	normal fiberglass tissue of 500 g/m^2	Polyester resin	3	Vaccum bag molding process
5	P5	Carbon fiber diagonal tissue of 200 g/m^2	epoxy resin	3	Vaccum bag molding process
6	P6	Carbon fiber unidirectional tissue of 410 g/m^2	epoxy resin	3	Vaccum bag molding process

2. Mould Release Agent: Formula Five mould releasewax (USA)
3. Hardener: metyle-ethyl-ketone peroxide 1%
4. Fiber glass: normal tissue of 500g/m^2

For vaccum bag molding process [8]

Technical characteristics:

1. Epoxy resin Epiphen RE 4020/ DE 4020 (France)
   Brookfield viscosity at 25^{0}C: 300mPa.s
   Density at 25^{0}C: 1150 kg/m^3
   Gel mass obtaining time on 20^{0}C: 45 min
   Thin layer hardening time on 20^{0}C: 8-9 h
   Complete polymerizing time on 20^{0}C: 14 days
   Aspect – transparent
2. Carbon fiber: diagonal tissue of 200 g/m^2
3. Carbon fiber: unidirectional tissue of 410 g/m^2
4. Perforated mold release sheet (Germany)

Technical characteristics:
   Maximum temperature: 80^0 C
   Diameter of holes: 0.4 mm
   Distance between holes: 10 mm
   Foil thickness: 0.025 mm
   Maximum delivery width: 1220 mm
   Maximum breakage resistance: aprox. 100 MPa
   Elongation at break: 80 %
   Density: 900 kg/m^3
5. Absorbing felt (Germany)
   Main material: polyester absorbing tissue
   Maximum work temperature: 205^0 C
   Thickness: 3-4 mm
   Density: 150 kg/m^3
   Maximum delivery width: 1520 m
6. Bag material: special vacuum foil
   Maximum temperature: 125^0 C
   Maximum pressure: 4 bar
   Thickness: 0.08 mm
   Delivery width: 1750 mm
   Elongation at break: aprox. 100%
   Density: 740 kg/m^3
   Styrene resistance: very good

The plates were codified with the letter “P” followed by two indices: for instance P1.2 The first notation indicates the type of the plates produced by a certain technological procedure and from certain constituent materials according to table 1.

The second index represents the position of the piece test cut out from the plate following the direction of the texture beginning from one margin (fig. 1).

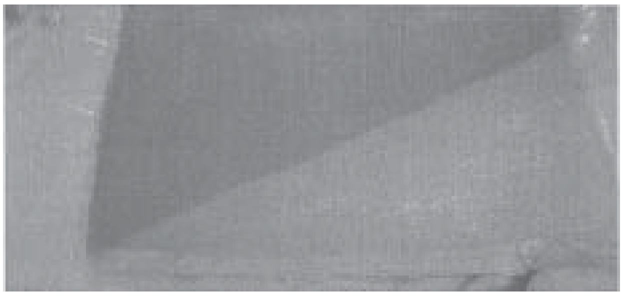

Fig. 1. Direction of the texture

Analysis of experimentally obtained plates

The technical characteristics of the PLATES obtained through different technological procedures are included in table 2.

P1 plate was made trough hand lay-up with three 500g/m² tissue layers, using classic tools, pressure rolls, model plate etc., obtaining a reinforcing degree of 64.51%. The disadvantage of this procedure is that we can not obtain an uniform pressure on the plate and because of this, there are other inconveniences like: unequal packing, unequal reinforcing degree, high anisotropic coefficient etc. These processes will influence in a negative way the break strength as bellow. In all experiments were used 3 reinforcement material layers observing the fact that the final thickness of the plate is not equal with the sum of the layers thicknesses due to the packaging and the interference of the fibers table 2).

P2 and P3 plates were made through hand lay-up also, from the same materials as the P1 plate, but at the end of the process a pressure of 2000 respectively 4900 Pa was applied. The purpose of this action was to obtain an uniform structure and to eliminate the excess resin. At the same time a higher reinforcement degree was obtained from 64.5% for P1 to 66.66% for P2 and 68.18% for P3.

Table 2

No	Notation Piece test	Weight of reinforced material (g)	Weight of composite plate (g)	Degree of reinfor cement (%)	Density of composite material (kg/m^3)	Thickness of a reinforced material layer (mm)	Number of layers	Final composite thickness (mm)
1	P1	60	93	64.51	1352.72	0.6	3	1.6
2	P2	90	135	66.66	1588.55	0.6	3	1.4
3	P3	90	132	68.18	1564.44	0.6	3	1.35
4	P4	90	100	90	1230.76	0.6	3	1.25
5	P5	48	65	73.84	1300	0.3	3	0.65
6	P6	37	46	80.43	920	0.4	3	1

As a conclusion, applying a pressure on the composite plate during the polymerization procedure, is useful because by eliminating the excess resin, the reinforcement degree will be higher, and finally it will achieve a higher mechanical strength, as it will be described in Chapter 4 of this work.

A much more performing procedure was used to produce P4, P5 and P6 plates, called vaccum bag molding process, well known in the technical literature but less used in practice because of its high manufacturing costs. The reinforcing material resin wet applied on the model, was covered by a perforated foil, and after, by an absorbent felt. The whole assembly was introduced in a special foil bag afterwards. After sealing, the bag was coupled to a vacuum pump, and the bag was vacuumed. During this time the atmospheric pressure will work on the plate attaining an uniform packing not dependant of the plate complexity. The purpose of the vacuuming is the eliminations of the air bubbles and the volatile compounds which are retained in the felt layer. The mould, was introduced in a drying chamber and kept at 60°C for 3 h for a more uniform and faster polymerization. During all this time, the pump was vacuuming (fig. 2).

The big advantage is that the atmospheric pressure works uniform on all plate points, so that the compact degree is uniform and constant on all the plate surface, and a high reinforcement degree (80-90%). The procedure is specific in the manufacturing of "high performance composite materials", used in aerospace industry.

At plate P4, at the same structure we obtain a reinforcement degree of 90 %, much higher that for P1, P2 and P3 (table 2).

P5 and P6 plates belong to the "high performance composite materials", using epoxy resin reinforced with carbon fiber weft, diagonal type of 200 g/m^2 and with carbon fiber weft unidirectional type of 420 g/m. The obtained reinforced degree was 73.84 % for P5 plate and 80.43 % for P6 plate.

Measuring the strength resistance for composite plates

The measuring of the mechanical characteristic by strength test has been made according to SR EN ISO 527-1/2000 and SR EN ISO 527-5/2000 standards. The method consists in application of load along central axis of a sample, with a constant speed, until the sample is breaking or until the load or elongation has reached a pre-established value. For strength test we have taken 5 analytical sampling on each plate, using cutting device with a diamond cutting disk, with dimensions according to ASTM D3039-76 standard.

The strength test had been made on a universal testing machine, type HECKERL, provided with a input module of a testing data. The stress velocity was 0.2 mm/s, and for determination of a breaking strength (R_r) we used the following relation:

$$R_r = \frac{F_r}{S_0} \text{ [MPa]} \quad (1)$$

where:

F_r - traction force on sample breakage, in N;
S_0 - initial flat area section, in mm^2

The experimental results obtained were processed and introduced in table 3. The extreme values were eliminated from the determination of the medium breaking strength.

The experimental results allow a comparative study concerning the influence of reinforcing materials, reinforcing degree, and also of the technological procedures used in the research of the breaking strength of composite structures [7].

The breaking strength has increased from 246.32 MPa and a 64.51% reinforcing degree for fiberglass, to 1036.58

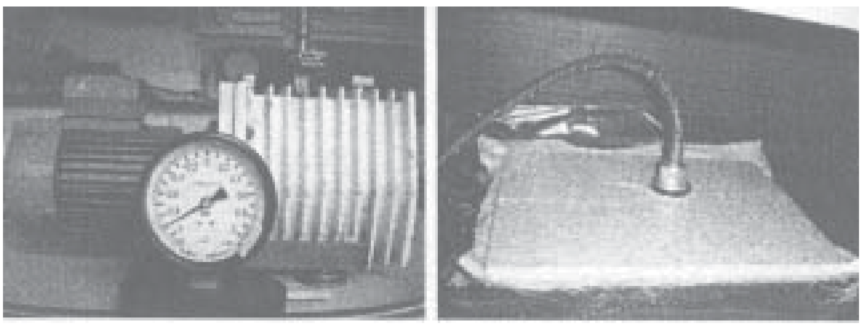

Fig. 2. Plate put in a stove under vacuum air pump action

Table 3

No.	Sample code		Sample dimension: width [mm]	Sample dimension: thickness [mm]	Sample section [mm²]	Maximum extension [mm]	Maximum force [kN]	Breaking strength [MPa]	Medium breaking strength [MPa]
1	P1	P1.1	20.2	1.1	22.22	7.33	5.197	233.88	246.32
2		P1.2	20.03	1.1	22.03	7.06	5.425	246.25	
3		P1.3	20.4	1.1	22.44	6.55	4.493	200.22	
4		P1.4	20.4	1.08	22.03	7.65	5.337	242.26	
5		P1.5	20.4	1	20.1	8.67	6.221	309.00	
6	P2	P2.1	20.3	1.3	26.39	6.71	7.056	267.37	292.14
7		P2.2	20.4	1.4	28.56	6.98	7.488	262.18	
8		P2.3	20.3	1.4	28.42	8.96	9.348	328.92	
9		P2.4	20.3	1.3	29.39	8.25	8.081	306.21	
10		P2.5	20.4	1.47	29.98	8.43	8.875	296.03	
11	P3	P3.1	20.5	1.4	28.7	9.00	9.909	345.26	325.56
12		P3.2	20.4	1.4	28.56	8.56	5.297	185.46 *	
13		P3.3	20.3	1.35	27.40	9.17	9.848	359.41	
14		P3.4	20.35	1.32	26.86	8.88	9.841	366.38	
15		P3.5	20	1.35	27	9.07	9.159	339.2	
16	P4	P4.1	20.6	1.4	28.84	7.42	6.526	226.38	234.78
17		P4.2	20.6	1.5	30.9	6.88	4.261	137.89 *	
18		P4.3	20.2	1.3	26.26	7.10	6.577	250.45	
19		P4.4	20.2	1.3	26.26	6.48	6.110	232.67	
20		P4.5	20.1	1.3	26.13	6.69	6.001	229.65	
21	P5	P5.1	19.87	0.85	16.88	5.70	8.226	487.32	504.31
22		P5.2	20.22	0.81	16.37	6.18	8.319	508.18	
23		P5.3	19.88	0.87	17.29	7.26	9.776	565.41	
24		P5.4	19.93	0.84	16.74	5.83	7.639	456.33	
25		P5.5	19.95	0.82	16.35	7.11	11.680	714.37 *	
26	P6	P6.1	20,	0.8	16	5.44	10.305	644.06 *	1036.58
27		P6.2	19.82	0.8	16.85	6.47	13.904	825.16	
28		P6.3	20,5	0.79	16.19	7.31	14.861	917.91	
29		P6.4	20	0.8	16	8.35	18.798	1174.87	
30		P6.5	20.2	0.8	16.01	9.79	19.667	1228.41	

*Values eliminated

MPa and to a 80.34% reinforcing degree for the carbon fiber. For P1-P3 plate reinforced with the same fiberglass plate with 500g/mm², the breaking strength increased with 43.13%, although the reinforcing degree increased only with 5.68%. This is due to a significant influence of technological procedures, especially to hand lay-up with the pressure that will eliminate the excess of resin and will increase the reinforcing degree. At P4-P6 plates we applied a higher technology: Vaccum bag molding process, the packing is made by the atmospheric pressure. Using vacuum we eliminate the air from the enclosure of the molding and the volatile substances produced during the resin polymerization. In this stage the pressure is constant in any point of the plate, which is a benefit for the composite structure; the anisotropy degree is decreasing significantly, resulting an increase of reinforcing degree. This is represented in diagram-result (Diagram P4), the diagrams for those 4 samples being almost identically (the minimum result was eliminated).

At the P4 plate, although the reinforcing degree increased with 32% beside the P3 sheet made by the same material, the breaking strength decreased with 33.4 % contrary to our expectations (repeating the experiment, the results is the same). The explanation is that at high reinforcing degree, approximately 90%, although we used the “vaccum bag molding process”, the soak of reinforcing material in resin is uneven, remaining some dry areas that will reduce significantly the resistance of the composite structure. In conclusion, according to the technological conditions, reinforcing material, resin viscosity, pressure and technological procedures there is an optimum maximum value of reinforcing degree, for which we can obtain high breaking strengths.

In figure 3 is presented the curve of traction strength according to the movement of the crossbar of testing machine, using Excel Soft. From each plate were cut out 5 samples that were tested in the same conditions, and the variations curves of the force is represented in the same diagram. It is pointed out the anisotropy phenomenon specific to the composite materials. In the first part the variation is almost linear, reaches a maximum value and after that the breakage will follow (fig. 3). We may say that the material is behaving like a plastic material; the size of the plateau region will increase with the increasing of the breaking strength (see the P5 and P6 plates reinforced with carbon fibers).

Interesting results were obtained for P5 and P6 plates of carbon fibers. Although the value of reinforcing degree are approximately equal (73.8% °i 80.43%), the breaking strengths are very different R_r=504.31 MPa for P5 plate and R_r=1036.58 MPa for P6 plate- this is due to the structure of the reinforcing material, carbon fibers type diagonal at P5, and unidirectional at P6. The manufacturing procedures of plates were the same, vaccum bag molding process.

The wide differences between the minimums and the maximums of the breaking strengths of the samples cut out from the same plate (22% la P5 °i 26% la P6) is explained by the technological difficulties to obtain an uniform structure of the fibres on the width of the plate during the manufacturing.

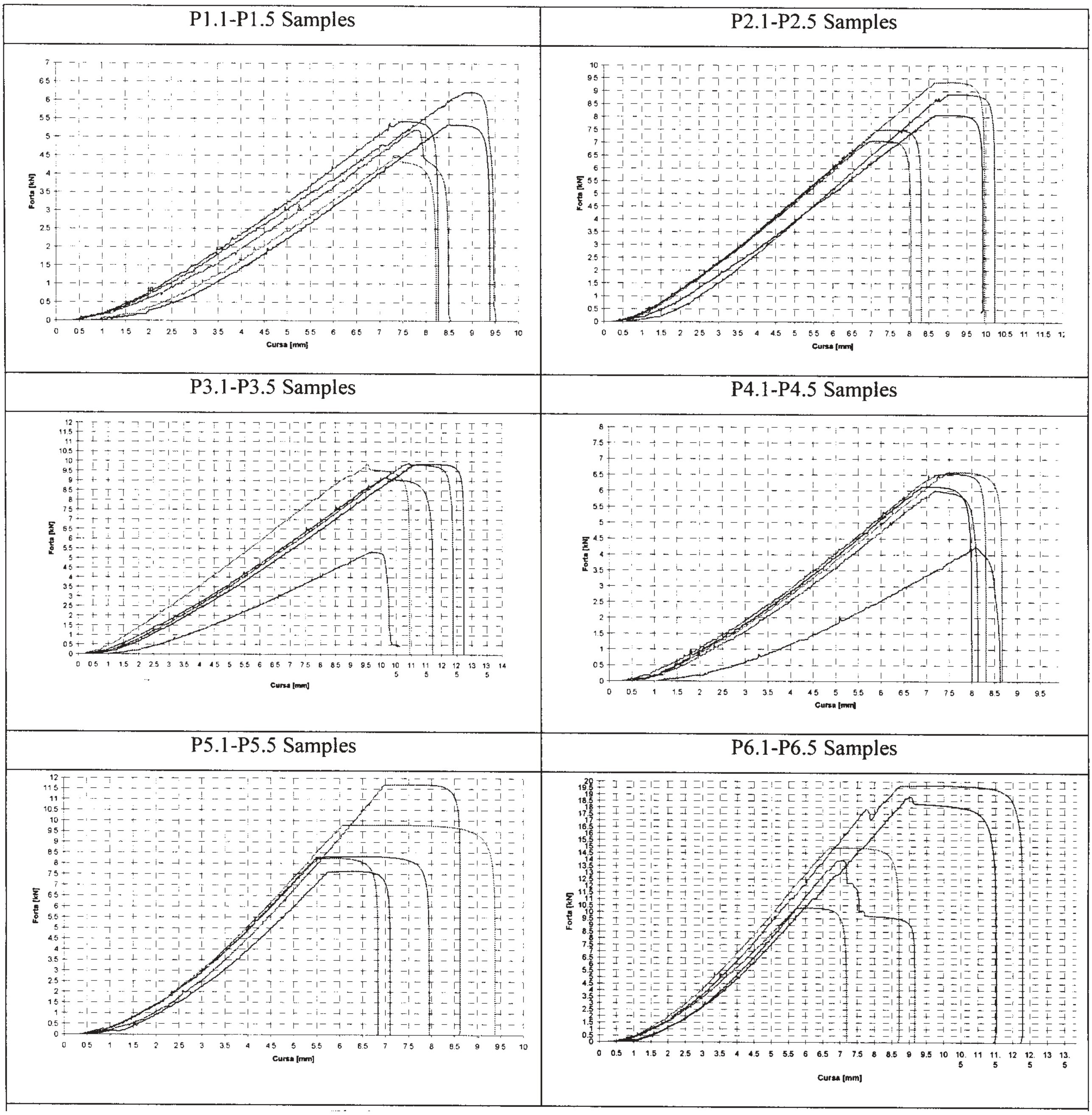

Fig. 3. The influence of the force depending on the race

Conclusions

The experimental research made in this study are leading us to the following opinions and conclusions:

- the mechanical behavior of the polymer-composite materials depends mainly on the nature the reinforcing material, reinforcing degree and the technological procedure;

- the mechanical characteristic of the composite structures obtained by “hand lay-up” are lower than those obtained by “hand lay-up with pressure” or “vaccum bag molding process”;

- the increasing of the reinforcing degree leads to higher mechanical characteristics of the composite are as long as the conditions of the technological procedures are strictly regarded;

- there is an optimum reinforcing degree according to the nature and structure of the reinforcing material, resin viscosity and the chosen technological procedure;

- the structure of the reinforcing material will influence the mechanical characteristics- the more longitudinal fibers are disposed in volume unit on the stress direction, the better will stand the composites on that direction;

- the procedure vaccum bag molding process is much more expensive, but more performing, being recommended for obtaining a “high performance composite”.

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