Analyzing Some Characteristics of a Cylinder-like Shape Fiberglass-Epoxy Resin Composite

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Abstract - **This paper introduces a new epoxy resin based composite material, reinforced with glass fibers, called Rotasteclofirep, manufactured by S.C. Electroputere Company, Romania. The first part of this paper includes some references concerning the constituents and the manufacturing modern technology of the composite under study. The second part presents a performance evaluation of the tested composite, based on experimental results provided by determination of its main physical and mechanical properties. The tests we are referring to in this paper are: the determination of compressive strength, static bending strength, Charpy shock resistance, the volume and surface resistivity, the withstand and breakdown voltages and thermal stability. These tests were performed in specialized Romanian laboratories. The products obtained by using Rotasteclofirep material, have low weight, very good mechanical properties, high resistance to chemical agents and a good behavior in terms of dielectric and thermal properties. These outstanding proprieties qualify this material to be used as electric insulator in whatever requiring insulation certain part of any electrical device. The Romania based S.C. Electroputere Company already uses Rotasteclofirep in the construction of transformers, load tap switches and electrical machines. This new Rotasteclofirep material could be delivered as tubes, cylinders and parallelepiped-like parts at any required dimension variety, on a large range of customer's demand.**

Keywords - *composite material, fiberglass, epoxy resin, rotasteclofirep, mechanical properties, electrical properties*

I. INTRODUCTION

Modern technology requires materials having rigidity, mechanical strength, high toughness and lightness. Often they have to provide some decent electrical and thermal properties. No single material makes possible to combine these characteristics, and to achieve what is necessary in using a composite material. In this area, the fiber-reinforced polymer matrix composite materials are the most used in industrial fabrication [1-5].

The purpose of the paper is to introduce Rotasteclofirep which is a new epoxy resin based composite material reinforced with glass fibers, whose properties recommend it for its use in various industrial applications. This composite material was designed and manufactured by S.C. Electroputere Company, Romania. Some experimental results obtained in determining the characteristics of Rotasteclofirep are presented in the paper.

II. INTRODUCING OUR COMPOSITE MATERIAL

Rotasteclofirep material is a composite material based on epoxy resin reinforced by glass fibers [6].

A. Reinforcing fibres

The main reason the Roving EC 15-1200 or Roving R 2119 glass fibers were used as reinforcing material into Rotasteclofirep is that they are actually the most widely used because of their properties and moderate cost [6, 7]. Like any other glass fiber, Roving-type fibers provide a linear elastic mechanical behavior.

We know that the macroscopic properties of a composite are highly dependent on the physical and chemical characteristics of the interfaces between the fibers and the matrix. The load transfer between the matrix and reinforcing material has to be done optimally, so it comes often necessary to increase the contact quality between the fiber and the matrix [1, 2]. This led, in the case of glass fiber, the development of a coupling agent. This coupling agent is, in fact, a chemical reagent, having the capability to chemically bond both with the organic matrix and the surface of the glass fiber. In the case of fiberglass, this coupling agent has, also, to protect the physical integrity of the fiber while handling it.

B. Matrix

The thermo set matrix of Rotasteclofirep is actually a mixture of Dinox-type resin, Octarom E3-type hardener (or HY-905 CIBA) and an accelerator [6]. It provides a noticeable fluidity during implementation. Its mechanical behavior is kind of plastic [8].

Resistant glass fibers are embedded in the matrix that holds them in place and ensures the cohesion of the composite material as whole.

III. MANUFACTURING TECHNOLOGY

The Rotasteclofirep composite is obtained by winding technology of the glass fibers impregnated in the epoxy resin through a warmly polymerization, all around of a cylindrical or a parallelepiped-like support which constitutes the body of resolution [6].

The manufacturing process is conducted through a computer program that allows setting the initial values and continuous control of the following parameters:

- the achieved yarn tensile force;
- the number of glass fibers wrapped all together and simultaneously and their winding angle;

- period of time and temperature of the warmly polymerization process of the impregnating mixture.

In the same time, the computer program enables the user to stop the installation functioning when warned that the cylinder outer diameter prescribed value was achieved.

The products obtained by using this technology, especially insulating tubes and cylinders, have low weight, very good mechanical properties, high resistance to chemical agents and a good behavior in terms of dielectric and thermal properties.

The customer's specific requirements in terms of dielectric and mechanical properties can always be satisfied by correspondingly adapting the volume ratio between the matrix and the reinforcing material and/or by adapting the parameters of the fabric technology. The dimensions of a certain profile can also be adapted, on customer's demand. Cylinders made of Rotasteclofirep and having different dimensions are shown in Fig. 1.

IV. EXPERIMENTAL

In order to determine and assess the characteristics of the Rotasteclofirep material, some tests were performed in specialized laboratories of the University of Craiova, SC Electroputere and ICMET, Craiova, Romania. In this paper we present only the results obtained for some tests that were carried out.

V. RESULTS AND DISCUSSION

The tests referred into this paper are the determination of compressive strength, static bending strength, Charpy shock resistance, the volume and surface, the withstand and breakdown voltages, thermal stability and they were carried out according to the following Romanian regulations in testing procedures: STAS 5873-83 [9], STAS 5874-83[10], STAS 5801-86 [11], STAS 6107-81[12] and STAS 6174-73 [13] .

A. Compressive strength

Tests were performed on five samples (made of the material Rotasteclofirep). The load at the time of fracture for each specimen was determined. Test speed was set at 0.9 mm/min. Geometrical dimensions of the specimen as well as the sample breaking load value F are shown in Table I.

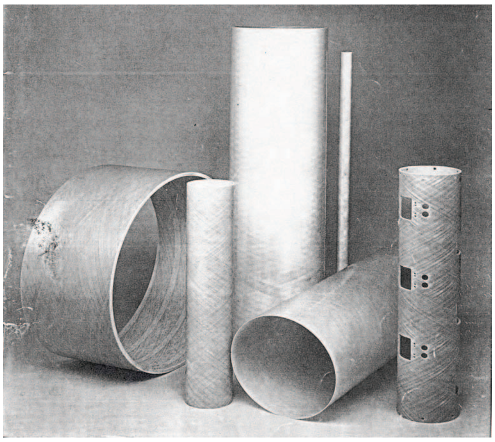

Fig. 1. Rotasteclofirep cylinders.

Compressive strength was calculated as the ratio between the load corresponding to the moment of sample breaking, F, and initial sectional area of the sample, S_o. Calculation results are summarized in Figure 2. Considering the values presented in this figure, the following average results for compressive strength, σ_c =29.458 MPa. Minimum value was 10 MPa, so the material meets the requirements.

B. Static bending strength

Tests were performed on five samples (made of our material of interest). Geometrical dimensions of the specimen and the load value, F, are presented in Table II. Test speed was set at 2 mm/min. To calculate the static bending strength, the following equation was used:

$$\sigma_i = \frac{3 \cdot F \cdot L}{2 \cdot b \cdot h^2} \quad (1)$$

where L = 60 mm is the distance between supports. All the rest of the measured quantities appearing in the formula have meanings and are expressed in units of Table II. The results of this calculation are summarized in Figure 3. Using the values from this figure, the average value was determined for static bending strength, σ_c = 252.674 MPa. Minimum value was 50 MPa, so the material meets the requirements.

C. Charpy impact strength

Determination of Charpy impact strength was performed on five un-notched specimens. The distance between the supports was 60 mm. Geometrical dimensions of the specimens and the amount of energy consumed in order to break each specimen, by shock, are presented in Table III.

Charpy impact strength was calculated with the following formula:

$$a_n = \frac{A_n}{x \cdot y} \cdot 10^3 \quad [kJ/m^2] \quad (2)$$

where the measured quantities have meanings and are expressed in units of Table III.

The results of this calculation are shown in Figure 4 and the medium average value for Charpy impact strength is a_n= 31.064 kJ/m^2. Minimum value for this parameter was 2 kJ/m^2, so the composite material meets the requirements.

TABLE I.
GEOMETRIC DIMENSIONS AND LOADS OF SAMPLES FOR COMPRESSIVE STRENGTH TEST

Number of sample	Height [mm]	Width [mm]	Thickness [mm]	Load value at the breaking moment (F) [N]
1	29.8	9.8	15.2	4600
2	29.9	10.0	15.2	4640
3	30	10.1	15.1	5130
4	29.7	10.1	15.0	4460
5	29.6	9.9	15.1	3410

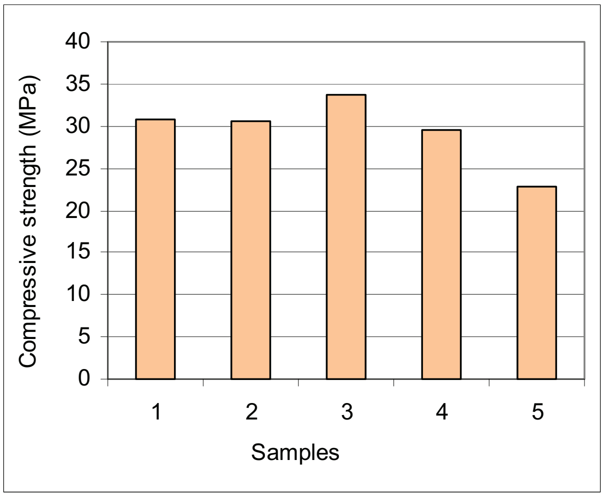

Fig. 2. Obtained values at compressive strength test.

TABLE II.
GEOMETRIC DIMENSIONS AND LOADS OF SAMPLES FOR BENDING STRENGTH TEST

Number of sample	Length (l) [mm]	Width (b) [mm]	Thickness (h) [mm]	Load value (F) [N]
1	80.1	10.2	4.1	485
2	80.2	10.1	4.2	510
3	80.0	10.0	4.1	465
4	80.1	10.1	4.1	500
5	80.0	10.1	4.1	470

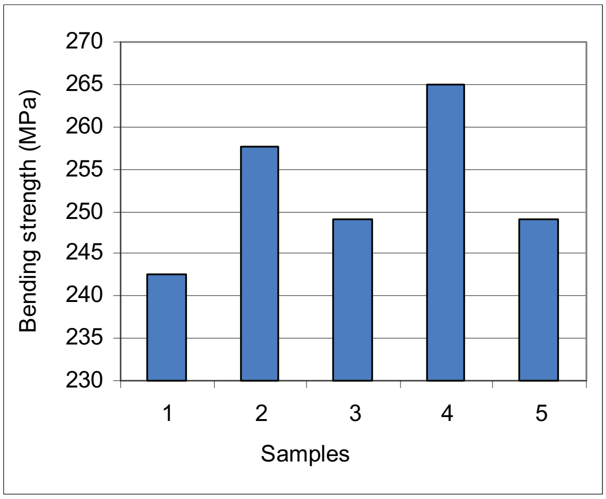

Fig. 3. Obtained values at static bending strength test.

D. *Volume and surface resistivity*

Determinations of volume resistivity and surface resistivity were made on five specimens. These samples were disc-shaped. Their diameter was 100 mm and their thickness was 3 mm. It was applied a voltage of 500V (DC power supply) for one minute at a temperature of 20°C and humidity of 65%.

Prior to testing, specimens were maintained for 120 hours at a temperature of 40°C and a relative humidity of 93%, according to STAS 8393/4-81 [14].

Values for volume resistivity and surface resistivity are summarized in Figure 5 and Figure 6, respectively. The medium average results were: $\rho_V=7{,}3\cdot10^8$ Ω·m and $\rho_S=3{,}96\cdot10^{10}$ Ω. Minimum values recommended for electrical equipment with nominal voltage greater than 127 V were 10^8 Ω·m and 10^{10} Ω and, therefore, the material was within the recommended values.

E. *Withstand and breakdown voltages*

In order to perform this test we used two categories of three tubular samples each, having the following diameters (external and internal, respectively) and lengths:

1. 1st category: 3 samples Φ16mm x Φ8mm x 163mm;
2. 2nd category: 3 samples Φ28mm x Φ12mm x 185mm.

TABLE III.
CHARPY IMPACT STRENGTH DATES

Number of sample	Length (l) [mm]	Thickness (x) [mm]	Width (y) [mm]	Value of impact energy (A_n) [J]
1	80.3	9.8	4.1	1.3
2	80.4	9.9	4.1	1.3
3	80.2	9.7	3.9	1.1
4	80.1	9.6	4.0	1.2
5	80.2	9.8	4.0	1.2

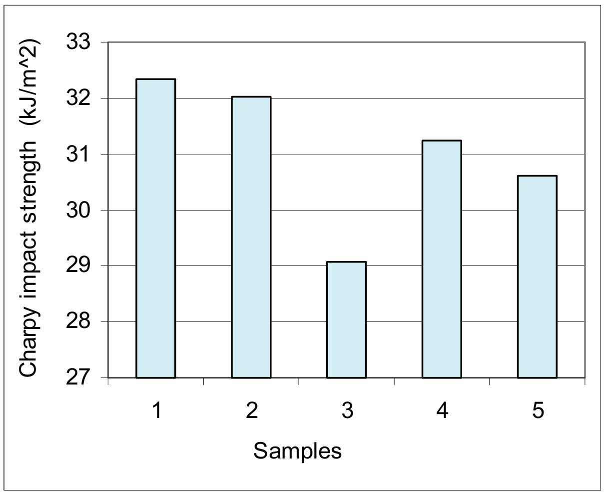

Fig. 4. Obtained values at Charpy impact strength test.

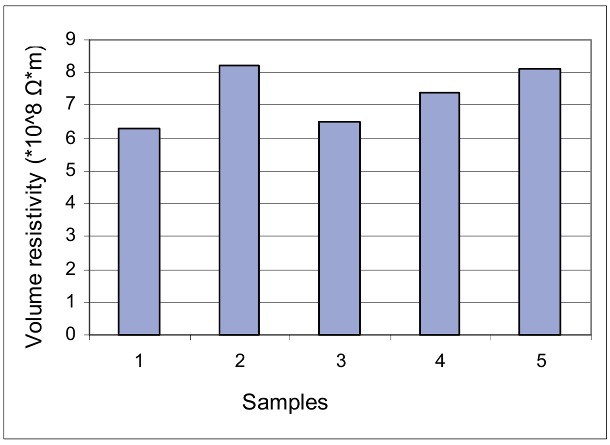

Fig. 5. Values of volume resistivity for each of the tested samples.

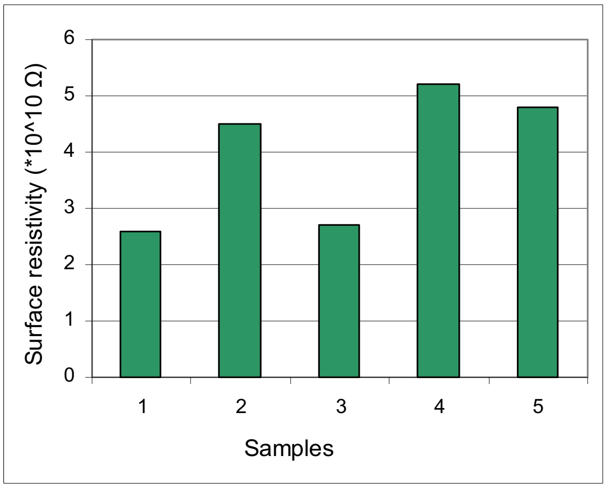

Fig. 6. Values of surface resistivity for each of the tested samples.

The 50 Hz AC withstand voltage was applied for one minute on the samples, as follows: 35kV for the first category and 55kV for the second one. All this time, all samples were completely immersed in a large enough quantity of TR-30 transformer oil at the environmental temperature. All six samples passed this test.

The determined value of the breakdown voltage was bigger than 75kV for the samples concerning the first category and bigger than 100kV for the samples concerning the second one.

F. Thermal stability

Thermal stability was determined by Martens method, making tests on nine parallelepiped-like samples.

Geometrical dimensions of the tested specimens are shown in Table IV. The experimentally obtained values for temperature concerning each and every sample are shown in Figure 7, and the corresponding medium average value is 140^{o} C. While the temperature requested minimal value is 100^{o} C, it comes obvious the material meets all thermal stability requests.

G. Discussion

Experimental results obtained from mechanical tests show that the determined values are much higher than those required. Therefore, Rotasteclofirep material shows a very good mechanical behavior at a density between 1.7 and 1.75 g/cm^3 (guaranteed by the manufacturer) [15, 16].

The experimental results obtained at the withstand voltage test and the breakdown test as well as those obtained for the volume resistivity and surface resistivity lead us to the conclusion that the Rotasteclofirep owes really good dielectric properties.

More else, this new material proves a good Martens thermal stability as the obtained experimental results are showing in the III.F section.

VI. Conclusions

The experimental results presented in the paper show that as result of combining in a certain way, of several types of material, the Rotasteclofirep material was made up. This material has, as a composite, a set of physical and mechanical properties that no one of its constituents has.

TABLE IV.
Geometric Dimensions and Loads of Samples for Martens Thermal Stability Test

Number of sample	Length [mm]	Width [mm]	Thickness [mm]
1	120.1	15.0	10.2
2	129.0	15.1	10.2
3	120.1	14.9	10.1
4	120.2	15.2	10.2
5	120.1	15.2	10.1
6	120.3	15.1	10.2
7	120.3	15.0	10.2
8	120.2	15.1	10.2
9	120.3	15.0	10.1

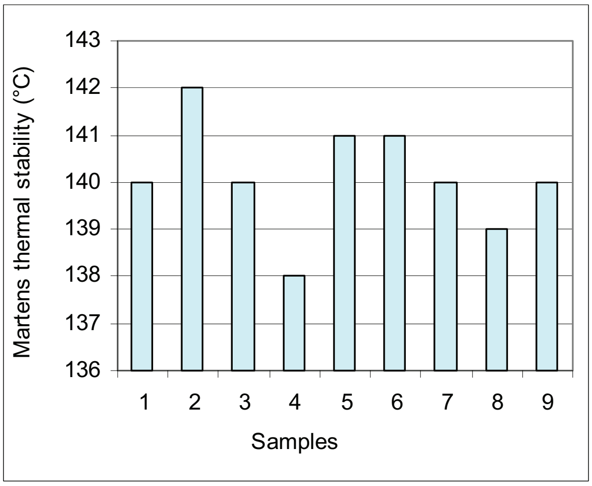

Fig. 7. Martens thermal stability for each of the tested samples.

Experimentally determined values of the features are similar to those of similar materials produced by famous companies such as the composite Rotafil developed by Maschinenfabrik Reinhausen (MR) in Germany [17].

The Rotasteclofirep material could be delivered as tubes, cylinders and parallelepiped-like parts at any required dimensional variety, on a large range of customer's demand.

These outstanding proprieties qualify this material to be used as electric insulator in whatever requiring insulation certain part of any electrical device.

Because it shows good properties, Rotasteclofirep material, the company Electroputere decided to replace some parts, made of classic materials with some made of the Rotasteclofirep material.

These replaced parts are used in the construction of transformers, load tap switches, electrical machines. They are, actually, tubes, cylinders as previously shown so that they could be, as well, sleeves, insulating feathers notch bolts, terminal crossing etc, all having a wide range of dimensions.

These Rotasteclofirep landmarks show the following main advantages in comparison with those used before replacement:

- Good mechanical properties, physical and chemical properties of Rotasteclofirep drived to the downsizing of replaced parts.
- The new parts are much lighter because, on the one hand, of their reduced size and on the other hand, of their small density due to Rotasteclofirep.
- Long life of Rotasteclofirep material, in electrical equipment operating conditions mentioned, leads to an increased reliability of the parts replaced.

ACKNOWLEDGMENT

This work was supported by S.A.Electroputere Company - Complex Equipments and Machinery Division, Craiova, Romania through the project 135/1996. We are also thankful to the specialists from Research, Development and Testing National Institute for Electrical Engineering who joined us in this research work.

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