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EXPERIMENTAL STUDY OF THE BEHAVIOUR OF COMPOSITE INSULATING MATERIALS FOR SPECIFIC TESTS

BY

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Abstract. Composite materials are cutting edge materials designed to achieve use function, chemical, physical, mechanical, electrical, magnetic, thermal properties of the highest quality. These materials have a wide use in various domains such as automotive industry, aeronautics, electrical engineering and electronics, etc. This paper proposes the presentation of experimental results regarding the burning behaviour and voltage impulses, determination of loss factor (tg δ) and dielectric rigidity for some composite materials which have a wide use in industrial achievements. Experimental determinations for burning behaviour, voltage impulses and dielectric rigidity were made with high performance equipment owned by the specialized laboratories of the National Institute for Research, Development and Testing in Electrical Engineering (ICMET). For the determinations regarding the loss factor (tg δ) were used the equipment from the laboratory of Electrotechnical Materials, Faculty of Electrical Engineering. The results showed that the tested materials behaved well and comply with the international standards.

Keywords: composite materials; fire testing; loss factor; dielectric rigidity.

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1. Introduction

The need to produce new high performance materials that meet the most demanding requirements of today's industrial development has led to the emergence of composite materials.

They are cutting edge materials that have chemical, physical, mechanical, thermic, optical, electrical, magnetic special properties.

Developing techniques and technologies to produce these materials on a large scale (special quality, low cost, increased reliability, etc.) has made the composite materials to be used with very good results in many diverse domains: from medicine to aeronautics, from sports equipment to the construction of road vehicles, from electronics to architectural constructions, etc. In this context, it is important and interesting the knowledge of their technical characteristics as well as the study and analysis of their behaviour in various situations. Therefore, this paper proposes to present the ex-perimental results regarding the fire behaviour and voltage impulses as well as the ex-perimental measurement of the dielectric rigidity and the loss factor (tg δ) for some composite materials (Fireproof Polypropylene, Compact Polycarbonate and Polymethyl metacrylate-PMMA Plazcast) for industrial use.

In the experimental measurements made for the determination of the fire behaviour, voltage impulse and dielectric rigidity were used advanced equipment (Fribourg Glow Wire Tester model 4150 and HILO TEST IPG 2025 and a 50 kV high voltage station) being in the provision of specialized laboratories of ICMET-Craiova.

For the determinations regarding the loss factor (tg δ) were used the equipment found in the laboratory of Electrotechnical Materials from the Faculty of Electrical Engineering, University of Craiova. The results showed that the tested materials behaved well and are in accordance with international standards (Ardeleanu *et al*., 2019).

2. General Information on Composite Materials

Composite materials, along with other special materials such as technical polymers, technical ceramics or some new metal materials, are part of the "new materials" category, which is a very important field in the technical and technological development of the world today (Ispas, 1987; Sima, 2017).

Composite materials are a more and more commonly used solution in performing advanced structures, applicable in all industrial branches. Composite materials are, by definition, those materials made up of two or more components which form distinct phases and whose combination results in synergistic effects (Tărâță & Mangra, 1996). Thus it can be said that the composite materials are essentially materials with anisotropic properties, made of two or more materials, which through the performance technology allows only the use of good characteristics of the component materials, and the final product obtained has generally higher properties than each component element.

They exhibit mechanical, thermal, electrical, magnetic, optical properties.

Today, composite materials are used in a wide variety of fields, such as aeronautics, where they are used as reinforcement materials, aerospace and space shuttle structures, shipbuilding of various sizes for the shipbuilding industry, car bodywork construction and various parts in the automotive industry, electrotechnical and electronics industry, medicine in the manufacture of various limb prostheses, in construction, in the manufacture of sports equipment, etc (Ardeleanu *et al*., 2019).

3. Studied Composite Materials

A. General aspects regarding the studied materials

The studied composite materials are part of the category of materials used in civil and industrial construction (interior divisions, electrical installations, kiosks, greenhouses, displays advertisings, etc.).

The use of composite materials in architecture is due to the good properties they have like: low weight, low thickness, low execution time, good impact resistance (Nagy-Gyorgy, 2012). The studied materials were provided by ProSEP company and will be presented in the next sections.

B. Fireproofed polypropylene (PPs)

PPs are made from fireproofed polypropylene having a polypropylene homopolymer structure and can be extruded or pressed (Azmi *et al*., 2018).

The ignition of these plates is achieved by adding them a small amount of special additives such as organic bromine components combined with antimony trioxide.

In the event of fires, the PPs extinguish by themselves after the source of fire is removed due to the high percentage of oxygen they need to burn (28% oxygen, compared to 21% oxygen as normal in the atmosphere).

For industrial or building applications (Shah *et al*., 2013), this material is recommended for use in those applications where fire resistance and high chemical resistance are required. In the electric field, it is used for the realization of low voltage electrical panels.

C. Compact polycarbonate

Compact Polycarbonate (Coudrec *et al.*, 2014) plates are obtained by extrusion, being shinny on both sides, having excellent optical properties that can be made in transparent, opaque or colored. It is one of the most advanced transparent plastics materials, has high transparency, is very impact resistant, is lightweight, has a very long durability and can work in a very wide range of working temperatures and has a high resistance to fire.

Comparing it with glass, it can be said to be as transparent as glass is. Moreover, it is 200 times more impact-resistant than glass and is twice as lighter than glass at the same thickness. The ultimate bursting strength of compact polycarbonate sheets qualifies it as one of the best solutions for making single layer protective windows that have to withstand hammer or stones, etc.

Compact Polycarbonate can be bent in hot or cold atmosphere (under certain conditions) and can be easily processed. Due to their very good properties, Compact Polycarbonate sheets are widely used in the architectural field for roofs, skylights, sound barriers, windows for bus stops or telephone booths, as well as for other applications such as: safety glasses for cars, safety goggles, shields for law enforcement, machinery protection glass, etc.

D. Polymethyl metacrylate- (PMMA) Plazcast

PMMA Plazcast are characterized by a high degree of light transmission (92% for transparent plates) compared to glass, plus very good resistance to UV rays and aging. It is a rigid and impact-resistant material and weighs less than half the weight of a glass pane of the same size.

The properties of these types of boards recommend them to be used indoors and outdoors to produce luminous advertisements, volumetric letters, exhibition stands, luminous signs, greenhouse windows, skylights and many other products to attract the attention of passers-by (Ardeleanu *et al*., 2019).

4. Experimental Tests with the Presented Materials

The experiments were carried out with modern equipment in the ICMET-Craiova specialized laboratory. The experimental tests were carried out in accordance with the regulations and the existing standards.

A. The experimental tests for fire behaviour

Considering that the studied materials are used in architectural works, both indoor and outdoor, it was considered necessary to check their behaviour on fire (Ardeleanu *et al*., 2019). Fasteners were performed using the Friborg Glow Wire Tester model (FGWT) 4150 (Fig.1) according to the methodology in force (SR EN 60695-2-11).

Some technical characteristics of this equipment:

– temperature range 0–1,000ºC;

– timer function for 30 seconds and 60 seconds;

– high precision flame height gauge;

– timer for START BURNING and timer for STOP BURNING with digital display – resolution 0.1 second;

– separate switch for Wire ON/Wire Off;

– force for sample against glow wire 1 ± 0.2N created by weight;

– electrode current transformer has capacity for 150 A and an A-meter 0–200 A;

– Special Premium Grade thermocouple type K with stainless steel cover, diameter 0.5 mm.

– the low friction sample carriage has automatic return after 30 s driven by a pneumatic cylinder.

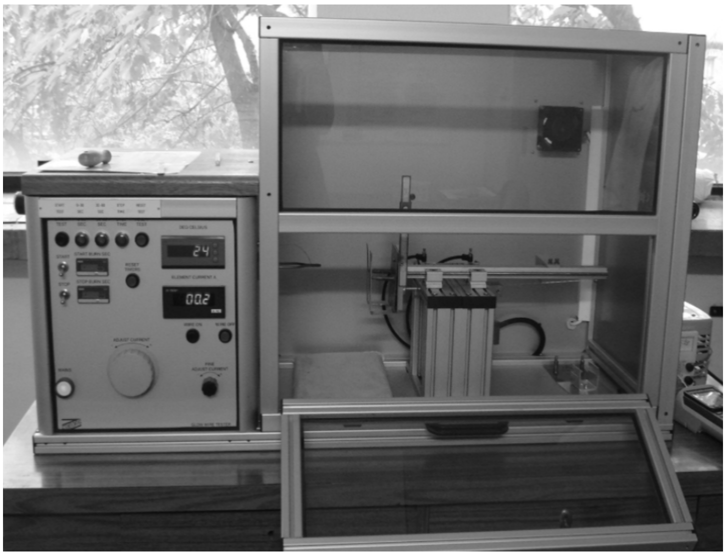

Fig.1– Friborg Glow Wire Tester model 4150.

The method used was that known in the literature as the "glow wire" method.

A calibration of the system was performed before starting the tests using a thin silver (99.9%) thin film having a melting temperature of 960ºC, the maximum material test temperature. In the Fig. 2 is shown an image during the testing of one of the studied materials.

The samples of materials studied had dimensions of 10 × 10 cm. The studied material samples were stored, before testing, for 24 hours in a room where the temperature was between 15ºC and 35ºC and humidity between 45% and 75%.

The materials were tested within a range of 30 minutes from the removal from the room, where they stayed for 24 hours, in accordance SR EN 60695-2-11. Tests for Polycarbonate and PPs were performed at 960ºC and for PMMA Plazcast, where no data on fire behaviour were known, a test at a temperature of 600ºC was performed.

Fig. 2 – Image during experimental determinations.

Only one sample of PMMA Plazcast was tested for fire behaviour, because there was no second test sample and no further tests could be performed at 960^{0}C. In the Fig. 3 is shown the three materials tested before the fire test and in the Fig. 4 after the test.

a) b) c)

Fig. 3 – Samples of studied materials
a) Compact polycarbonate, b) PPs,
c) PMMA Plazcast.

a) b) c)

Fig. 4 – Samples of studied materials
after the test of fire behaviour
a) Compact polycarbonate, b) PPs,
c) PMMA Plazcast.

The results achieved are summarized in Table 1. Considering that the materials were extinguished at t < 60 s, it can be said that they correspond to the existing standards with the Glow – wire flammability test method for end – products (GWEPT) index equal to 900.

Table 1
The Experimental Results Obtained for Fire Testing

No	Name of the material	$t_{application}$, [s]	$t_{ignition}$, [s]	$t_{flame\ extinguishing}$, [s]	GWEPT
1	Compact polycarbonate	30	12.6	39	900
2	PPs	30	2.6	32	900

B. Voltage pulse check

For the voltage pulse test, a HILO TEST IPG 2025 type device (Fig. 5) was used, alternating pulses + (plus) and – (minus), 5, 10, and 20 kV at 5 seconds intervals (IPG 2025). Only PMMA Plazcast and PPs were subjected to this test. The test results are summarized in Table 2.

Table 2
The Experimental Results for Voltage Pulse Check Testing

No	Name of the material	Voltage, [kV]	Mode of behavior
1	PMMA Plazcast	5	Good - no electrical discharge occurred
		10	Good - no electrical discharge occurred
		15	Good - no electrical discharge occurred
2	PPs	5	Good - no electrical discharge occurred
		10	Good - no electrical discharge occurred
		15	Good - no electrical discharge occurred
3	Compact polycarbonate	5	Good - no electrical discharge occurred
		10	Good - no electrical discharge occurred
		15	Good - no electrical discharge occurred

C. The dielectric rigidity

Dielectric rigidity is one of the important and defining characteristics in terms of electrical characteristics for electrically insulating materials (Ramana *et al*., 2011).

It is known that the dielectric rigidity represents the minimum value of the electric field intensity for which the insulating material penetrates (Ifrim & Noținger, 1979):

$$E_{str} = \frac{U_{str}}{d}, \quad (1)$$

where: U_{str} is the break-down voltage, d – distance between the electrodes.

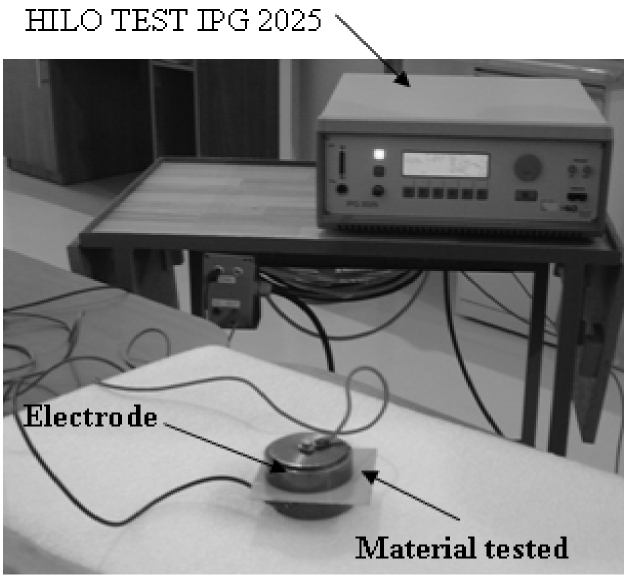

Fig. 5 – The experimental equipment for voltage pulse check.

Thus, it is important to know the value of the dielectric rigidity for the new materials of the type of composites that are used more and more today in technical applications. The test for dielectric rigidity was performed with a 50 kV a.c. in the specialized laboratory of ICMET-Craiova (Fig. 6).

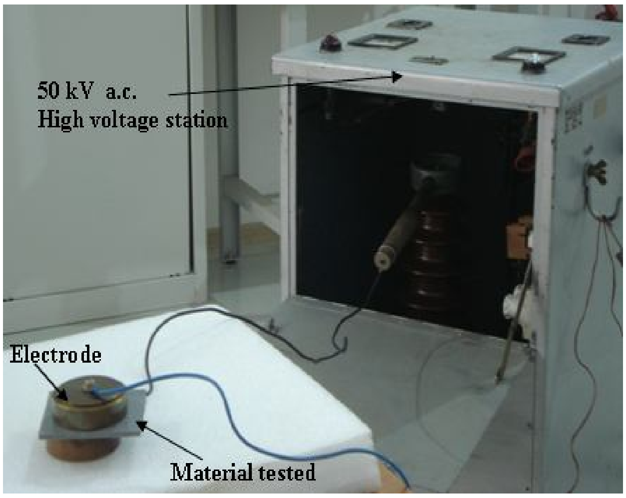

Fig. 6 – The experimental equipment used for the dielectric rigidity.

The tests were subjected to samples of PMMA Plazcast and PPs (Fireproof polypropylene) with dimensions of 10 × 10 cm. The test results are presented in the Table 3.

Table 3
The Experimental Results Obtained for the Dielectric Rigidity

No	Name of the material	U_{str}, [kV]	Depth, [mm]	E_{str}, [kV/mm]
1	PMMA Plazcast	15	3	5
2	PPs	16	5	3.2
3	Compact polycarbonate	20	3	6.66

D. Loss factor determination

Loss factor is a parameter that characterizes the value of total energy losses in dielectric materials, losses due to polarization, conduction or electric shock.

The angle δ represents the complementary angle to the phase of the actual exit phase between the electrical voltage and the electric current that crosses the dielectric between the condenser armatures of an electric capacitor (Ifrim & Noținger, 1979). Knowing the value of tg δ can provide specialists with information on the degree of aging of the respective insulation.

The experimental determinations were performed with the in the laboratory of Electrotechnical Materials of the Faculty of Electrical Engineering in Craiova.

In Fig. 7 the experimental setup is presented. A low voltage Schering bridge (40 V supply voltage, working frequency 50 Hz,...,30 kHz), a frequency generator and an oscilloscope were used in the experimental determinations (Morsalin *et al*., 2017; Putter *et al*., 2012). The experimental results are presented in the table IV.

The equation (2) was used to calculate the loss factor:

$$\mathrm{tg}\,\delta = A \cdot B \cdot f\,, \tag{2}$$

where: f represents the frequency [kHz], A_1, A_2 represent the values of the capacitances of the measuring kit, $A = A_1 + A_2$.

The depths were 3 mm for PMMA Plazcast, 5 mm for PPS and 3 mm for Compact polycarbonate.

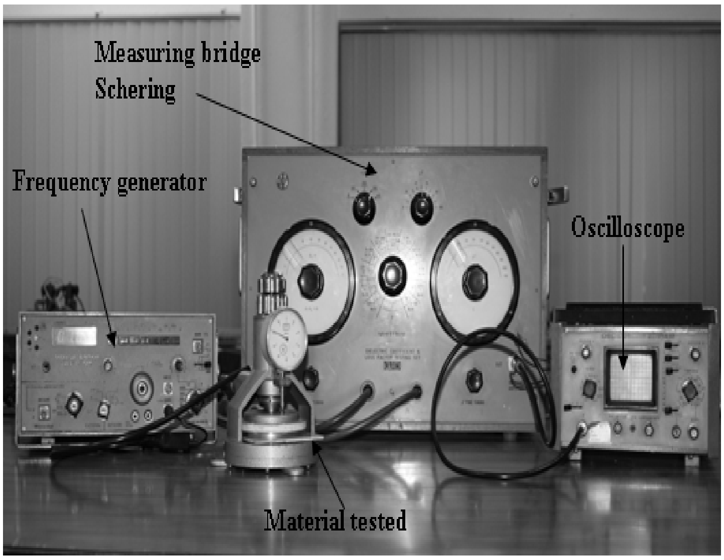

Fig.7 – The experimental equipment used for determination of the loss factor.

Table 4
The Experimental Results Obtained for the Loss Factor

No.	Name of the material	d [mm]	f [kHz]	A_1 [pF]	A_2 [pF]	$A=A_1+A_2$ [pF]	B	tg δ
1	PMMA Plazcast	3	1	9	0	9	10^{-2}	9×10^{-2}
			10	11	0	11	10^{-3}	11×10^{-2}
			100	10	0	10	10^{-4}	10×10^{-2}
2	PPs	5	1	14	0	14	10^{-2}	14×10^{-2}
			10	16	0	16	10^{-3}	16×10^{-2}
			100	16	0	16	10^{-4}	16×10^{-2}
3	Compact polycarbonate	3	1	15	0	15	10^{-2}	15×10^{-2}
			10	16	0	16	10^{-3}	16×10^{-2}
			100	16	0	16	10^{-4}	16×10^{-2}

5. Conclusions

The need to use materials that meet the most demanding requirements of industrial development in recent decades has led to the production of composite materials.

These cutting edge materials requiring advanced production technology have outstanding chemical, physical, mechanical, thermal, electrical, magnetic, etc. qualities being used today with great success in many fields such as medicine, architecture, electronics, electrotechnics, shipbuilding and aerospace, etc. In this paper we analysed some composite materials namely Flame Polypropylene, Compact Polycarbonate and PMMA Plazcast.

Considering that those materials have also been used in the architectural field (chisels, greenhouses, billboards, partitions, etc.), it was considered useful to check their fire behaviour and voltage impulse, with the possibility that in practice to be subjected to accidents with the appearance of an opened fire. The experimental results obtained showed that these materials (Compact polycarbonate and PPs) behaved well, according to international standards, with the GWEPT index equal to 900. Also it was found that the materials PMMA Plazcast, Compact polycarbonate and PPs performed well at the voltage pulse check testing.

The results obtained for loss factor, considering that the equipment used is one for didactic use, however, reveals that from the point of view of the dielectric losses these materials do not behave very well considering that for the usual electrotechnical materials tgδ has values between 10^{-4} and 10^{-1}.

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* * * *FGWT - Friborg Glow Wire Tester model 4150, datasheet, Friborg Testteknik AB, Sweden.*

* * * *IPG 2025 - HILO TEST IPG 2025 high voltage impulse generator,* disponibil pe https://www.hilo-test.de/products/product-categories/impulse-voltage generator /item/213-ipg-2025-en.

* * * *ProSEP – semifabricate din materiale compozite,* www.prosep.ro/produse/.

* * * *SR EN 60695-2-11- Incercări privind riscurile de foc /Partea 2-11: Încercări cu fir incandescent/încălzitor. Metodă de încercare a inflamabilitătii pentru produse finite (GWEPT).*

STUDIUL EXPERIMENTAL AL COMPORTĂRII MATERIALELOR COMPOZITE PENTRU TESTE SPECIFICE

(Rezumat)

Materialele compozite sunt materiale de ultimă generaţie concepute pentru a se obţine, funcţie de utilizare, proprietăţi chimice, fizice, mecanice, electrice, magnetice, termice cât mai bune.

Acestea au o largă utilizare în diverse domenii precum industria automobilelor, în aeronautică, in inginerie electrică, electronica, etc.

În această lucrare se propune prezentarea rezultatelor experimentale privind comportarea la foc şi impuls de tensiune, a factorului de pierderi (tg.δ) şi a rigidităţii dielectrice pentru câteva materiale compozite care au o largă utilizare în realizări de tip architectural.

Determinările experimentale privind comportarea la foc şi impuls de tensiune şi a rigidităţii dielectrice s-au realizat cu echipamente performante aflate în dotarea laboratoarelor de specialitate ale Institutului Naţional de Cercetare Dezvoltare şi Încercări pentru Electrotehnică (ICMET). Pentru determinarea factorului de pierderi au fost utilizate echipamentele din cadrul laboratorului de Materiale Electrotehnice, Facultatea de Inginerie Electrică.

Rezultatele obţinute au arătat că materialele testate s-au comportat bine şi corespund normativelor internaţionale.