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Innovative biocomposite derived from waste materials with applications in electrical domain

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Abstract. The article highlights the possibility of producing biocomposite material from plastic (e.g. polypropylene) and natural organic materials used as fillers (eggplant flour) which have applications in electrical domain. The right amount of material used as filler is evaluated using mechanical tests and dielectric spectroscopy in order to obtain an optimal structure biodegradable, making it suitable as a viable technical solution to partially replace electrical enclosures or different insulators.

Introduction

Continued growth of electrical applications requires materials with increasingly high performance: lighter, more flexible, more resistant to mechanical and thermal stress, with high or low electric conductivity, with greater resistance to environmental actions, with reduced power consumption (both for manufacturing as well for processing and use), with higher reliability, more sustainable and certainly cheaper. These types of materials were developed in short time, in many classes and the materials like composites and nanocomposite have recorded a significant advance, with practical applications in all fields. Obtaining biodegradable materials is an ever-present requirement in the rules on production of new material and especially environmental protection. A method of recovering plastics is by processing of mixtures using natural polymers for reinforcement, namely the production of composite materials with special properties [1]. Use of these materials in electrical and electronics is fully accepted, but their properties are not always appropriate for some applications.

Considering that demand for material in the wood industry is growing and forest resources are continuously decreasing, has led researchers to study and other non-wood lignocellulosic materials. The agricultural sector is the largest provider of lignocellulosic material as waste from cereals processing. The most frequently referred alternative non-wood materials are cereal straws such as rice and wheat straw flax and hemp and reed [2]. The criteria for the evaluation of materials, include general categories of resources, performance and pollution. The resources required for a material may be consumed in extraction, production, and use or disposal process. The performance refers to the energy and resources that can save or squander its use.

The principle of reducing hazardous substances, along with protecting the natural resources by developing alternatives to traditional materials or processes led to new concepts in the design, manufacture and application of such materials by offering an environmental advantage [3]. The interdisciplinarity and complexity of solution is given by designing biocomposite materials used in electrical engineering, obtained from virgin plastic (e.g. polypropylene) and natural organic materials used as fillers (eggplant flour). In different contexts, can be introduced vegetable oils, waxes or additives, or agents of consolidation, homogenization or binding, in order to obtain a biodegradable composite, which makes it suitable as a viable technical solution to replace partially housings of electrical equipments, transformers board in construction of the transformers and electric machineries or a different types of insulators.

Dielectric spectroscopy has proven a powerful tool to investigate in details the dynamical processes of composites materials. The dielectric properties of composite material are affected by several factors, e.g. molecular chain arrangement, amorphous and crystalline phase fraction, molecular weight distribution and temperature. This knowledge is important for the development of new materials and also to understand the eventual degradability of those [4].

Experimental part

Materials. Polypropylene and eggplant stalk residues were used as thermoplastic matrix and organic filler, respectively in order to obtain a homogeneous blend. The thermoplastic polymer polypropylene (PP), used as matrix material, was used as received. It had specific gravity of 0.90–0.91, melting temperatures of 165–171 C and crystallinity of 82%. Maleic anhydride grafted polypropylene (MAPP) was utilized as coupling agent. Eggplant stalk residues were granulated into 60-100 mesh size (149-250μm) flours using Wiley mill. Natural beeswax yellow with temperature melt 63°C was used as is.

Processing. The experimental design of the study is presented in Table 1. During the manufacturing process, depending on the formulation polypropylene (PP), eggplant flour (EF), maleic anhydride grafted polypropylene (MAPP), and wax were mixed in a high intensity mixer to produce homogeneous blend. Then this blend was compounded in a laboratory scale single screw extruder at 40 rpm screw speed and in the temperature range of 170, 180, 185, 190, 200 °C. Extruded samples were collected, cooled and granulated into pellets. Finally, pellets were compression molded in the hot press for 5 minutes at 175°C and cooled for 20 minutes. Panels with thickness of 1 mm and relative homogeneous were produced. See processing steps in figure 1.

Fig.1 Processing steps.
Extruder with single screw (left); Wiley mill (center); Hot press (right)

Table 1. Experimental design used in the study.

Sample	Polypropylene (PP) (%)	Eggplant flour (EPF) (%)	MAPP (%)	Wax (%)
PP	100	0	0	0
88PP/7EF/5MAPP+Wax	87,5	7,5	3	2
80PP/15EF/5MAPP+Wax	80	15	3	2
65PP/30EF/5MAPP+Wax	65	30	3	2

Methods. Mechanical properties like tensile strength, tensile modulus, elongation at break, flexural strength, flexural modulus, impact strength, were carried out with testing machine Zwick Roell z010 and pendulum impact tester Zwick Roell HIT5.5P according to following standards ISO 527-4, ISO 178, ISO 179-1. Broadband dielectric spectroscopy analysis were performed using a

Novocontrol GmbH Concept 80 Broadband Dielectric Spectrometer with an Alpha A analyzer over the frequency range of 10^{-2} Hz to 10^{7} Hz in combination with a Novocontrol Quatro temperature system providing control of the sample temperature with high accuracy, figure 2. The samples were sandwiched between two 20 mm gold plated electrodes and tested within ZGS Alpha Active Sample Cell. The test temperatures were 20°C [5].

Fig. 2 Broadband dielectric analyzer Concept 80 Novocontrol GmbH,

Results and discussion

Tensile properties. The mechanical properties for studied blends are presented in Table 2. In terms of technical difficulties, the thermodynamic mixing of the components may not lead to obtaining truly homogeneous products. A large amount of wax or vegetable oil is not desired because this can reduce the adhesion between fibers and polymer matrix. This can be a problem because it forms a biphasic structure, interactions between the two phases, at the interface, determining the properties of new material. In this case the situation at the interface between the two phases is very important. A high interfacial tension and poor adhesion between phases, associated with high viscosity, specific to macromolecular compounds leads to difficulties in obtaining the desired degree of dispersion, instability in machining operations, phase separation during subsequent processing and use. Poor adhesion between phases leads, on the one hand, to a poor mechanical behaviour and on the other hand makes it impossible to achieve a structured with homogeneous morphologies [6].

Table 2. Mechanical properties for studied blends.

Sample	Tensile Strength (MPa)	Tensile Modulus (MPa)	Elongation at Break (%)	Flexural Strength (MPa)	Flexural Modulus (MPa)	Impact Strength (J/m)
PP	13,83	512,15	3,01	28,79	1567	15,94
88PP/7EF/5MAPP +Wax	10,52	557,02	2,48	14,32	1022,33	14,38
80PP/15EF/5MAPP +Wax	10,74	609,027	2,2	13,03	1110,47	12,41
65PP/30EF/5MAPP +Wax	10,12	629,74	2,15	15,93	1346,25	12,19

The mechanical characteristics (figures) show that for materials with a minimum of added both elongation at break, figure 3 and impact strength, figure 4 has the highest values and decrease with increasing percentage of filler material. This is because by adding eggplant flour composites become more rigid and affinity in amorphous state decreases, even if they entered compatibilizing additives and adhesives. Flexural strength is halved for all mixtures studied because they have lost elasticity through EF mixing, figure 5. A decrease is observed for tensile strength which confirms, once again, brittle behavior due to poor adhesion between PP and EF natural material break, figure 6.

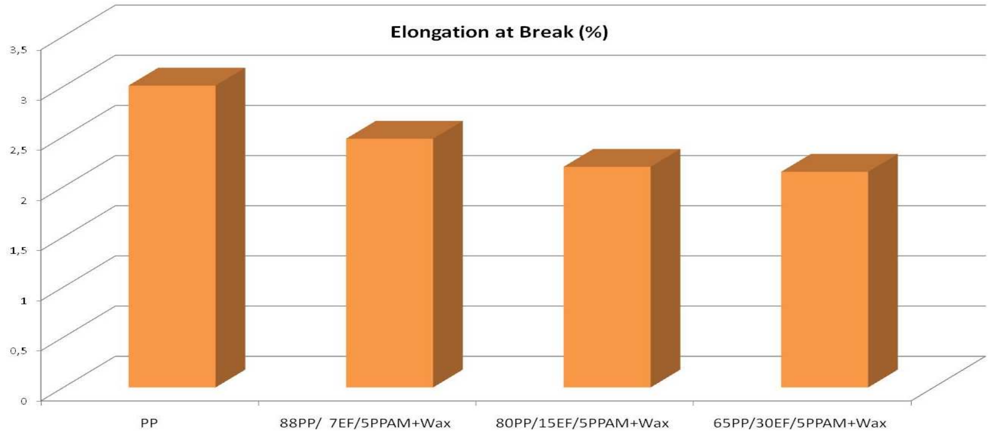

Fig. 3. Elongation at break for studied blends

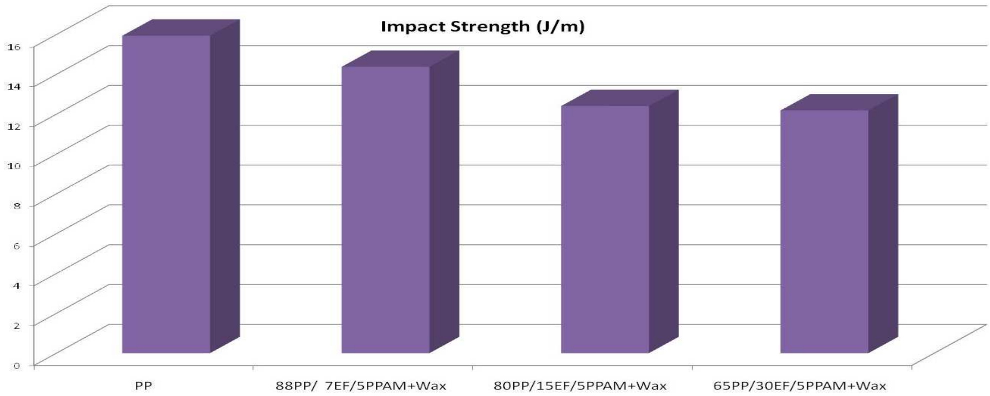

Fig. 4. Impact strength for studied blends

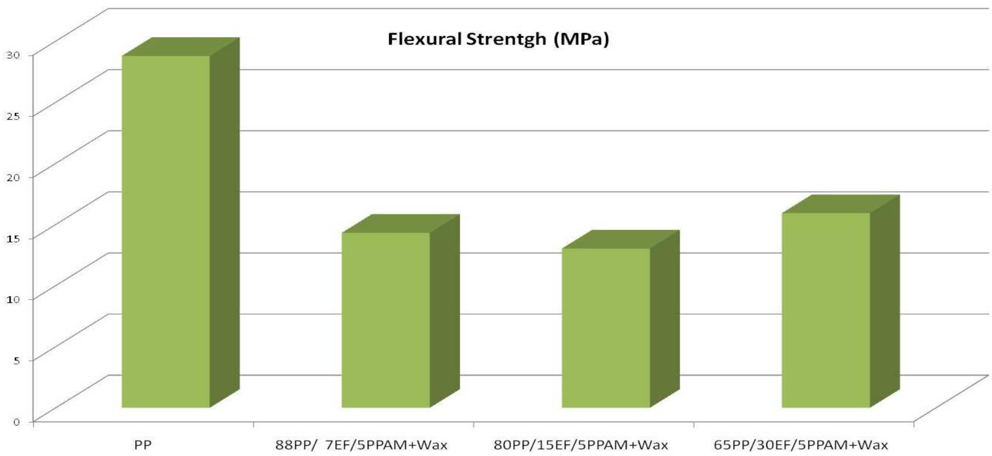

Fig. 5. Flexural strength for studied blends

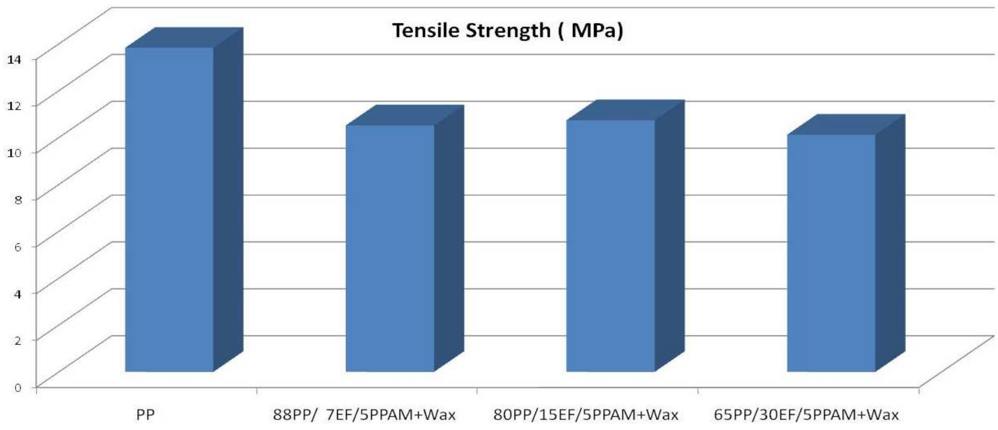

Fig. 6. Tensile strength for studied blends

Broadband Dielectric spectroscopy analysis. Dielectric characteristics analysis indicates that the composite material with 65PP/30%EF/5MAPP + Wax has remarkably high dielectric constant, being at industrial frequencies with 100% higher than the compound with 88PP/ 7EF/5MAPP+Wax. As expected, the highest values, both for dielectric constant and loss are recorded if the maximum addition of eggplant flour, figure 7.

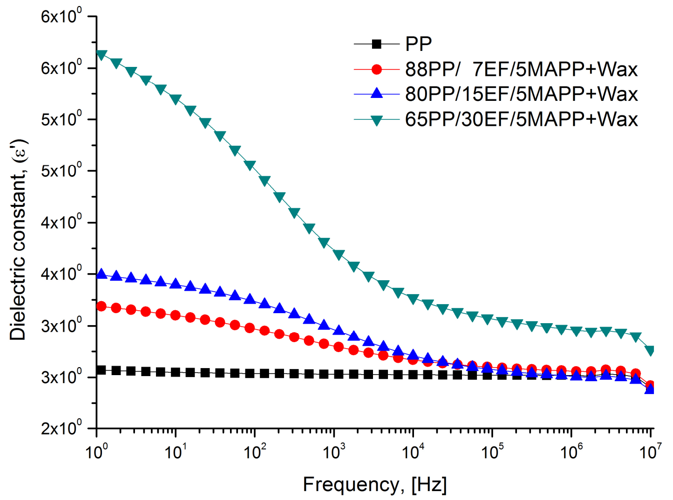

Fig. 7. Variation of dielectric constant (ε’) function of frequency for studied blends

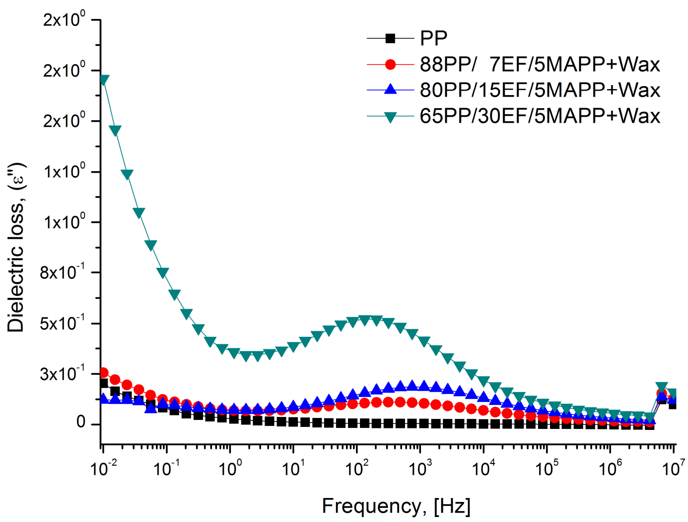

Fig. 8. Variation of dielectric loss (ε") function of frequency for studied blends

Specific dielectric losses due to polar character of eggplant have a high value at 1 kHz due to increasing percentage of eggplant flour. A novel aspect is that the hygroscopicity of the material which makes flour with increasing percentage of eggplant to identify significant losses by conduction phenomena, figure 8.

The tan δ curves follow the shape of the correspondent loss factor for this biocomposite. Significant increase of tan δ was found especially for the frequency 1 kHz. For 65PP/30%EF/5MAPP + Wax, there is a sudden jump in tan δ just like in the case of loss factor, figure 9.

Besides permitivity, loss factor and tangent (tan δ), real conductivity of the dielectric materials was also analyzed, figure 10. The conductivity increases with increasing frequency and was found to be strongly dependent on EF content as is observed in range of frequency between 1kHz up to 1MHz, and the weakest conductive effect composite was registered for 88PP /7%EF/5MAPP + Wax. Like conductivity, the specific resistance was found to be strongly dependent on EF content and decreases with increasing frequency, figure 11.

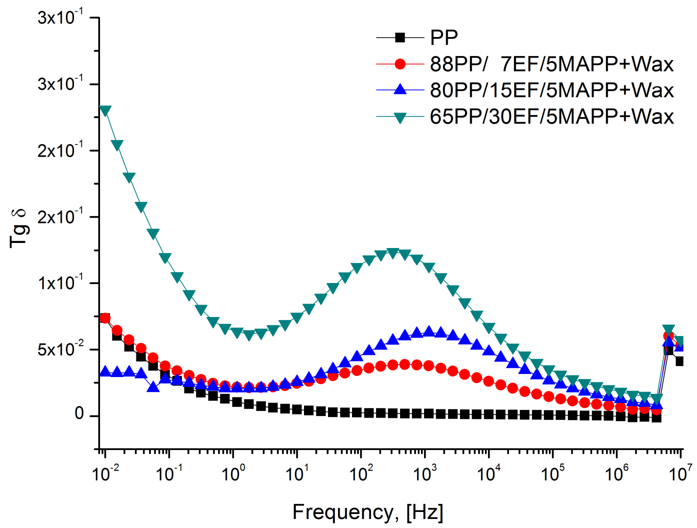

Fig. 9. Variation of tg(δ) function of frequency for studied blends

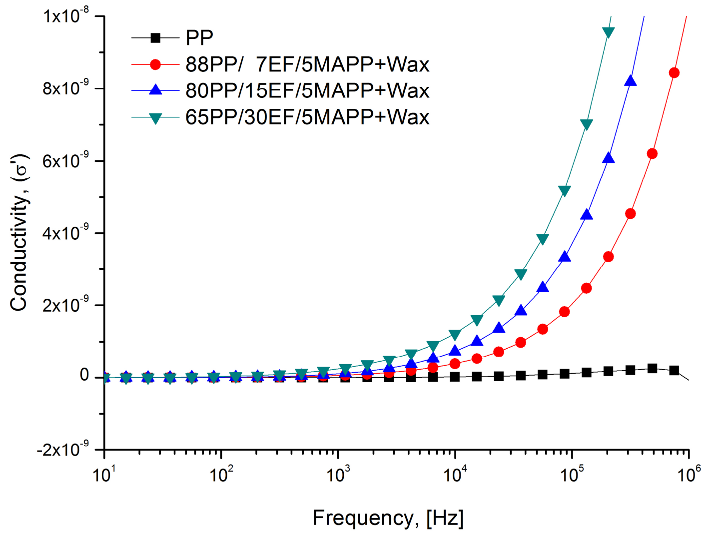

Fig. 10. Variation conductivity (σ') function of frequency for studied blends

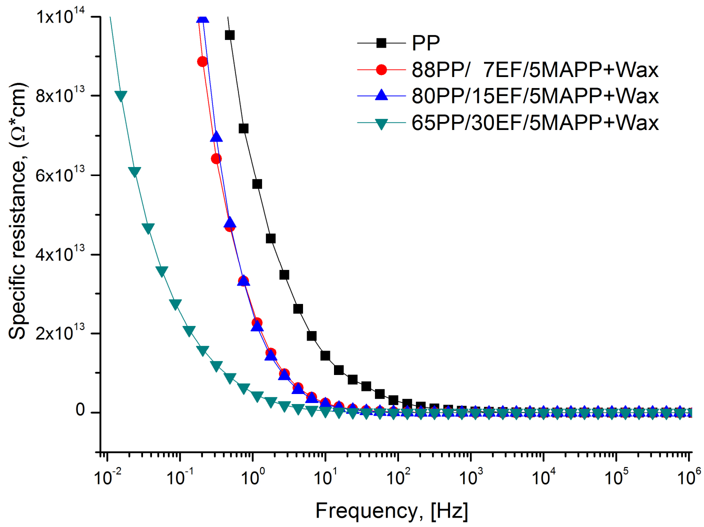

Fig. 11. Variation of specific resistance function of frequency for studied blends

Conclusions

Obtaining biodegradable materials is an ever-present requirement in norms of production of new material and especially environmental protection. Biocomposite materials were obtained from virgin plastic (e.g. polypropylene), natural organic materials used as fillers (eggplant flour) and waxes with potential application in electrical engineering like housings of electrical equipments, transformers board or a different types of insulators.

The results of mechanical test show a different behavior of blends function of amount of filler used in the system. As long as the amounts of filler increase the biocomposites become more rigid and amorphous affinity decreases. Also a large amount of wax is not desired because this can reduce the adhesion between fibbers and polymer matrix.

Taking into account both dielectric and mechanical properties, it seems that the biocomposite material with 65PP/30%EF/5MAPP + Wax has a remarkably high dielectric constant value, being at industrial frequency with 100% higher than the compound with 88PP /7%EF/5MAPP + Wax. From dielectric analyze can see that these materials can be tested for electrical applications like insulation capacitor, especially at industrial frequencies.

The physical-mechanical properties and biodegradability of the biocomposites depend both on the filler type component introduced, as well as its proportion. If the proportion of natural polymer, incorporated in the synthetic polymer matrix, exceeds 10%, the physical and mechanical properties will change, and induction period of biodegradation will be smaller and once the natural component disappear, will disappear in time and synthetic polymer that which will decay in very small fragments.

Increasing the proportion of natural ingredients to 40-60%, physical and mechanical properties are maintained within acceptable limits, and with the introduction in composite of vegetable oils and natural waxes biodegradation rate will increase significantly.

The potential reserves by plant materials are provided by woody plants and annual form cereal straw, crops, textiles and agricultural, and the main polymers of biomass (cellulose, hemicelluloses and lignin). Cellulosic material impregnated with waxes, are used because of excellent dielectric properties.

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