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INFLUENCE OF SILVER NANOPARTICLES ON MECHANICAL CHARACTERISTICS OF ARBOBLEND V2 NATURE LIGNIN-BASED POLYMER

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Abstract: The need to find materials for various common objects and more reliable and less expensive production is a major concern of society and scientists in recent decades, due to the dramatic decline in available stocks of materials from low renewable resources and massive pollution caused by the production of cement, brick, plastics or other similar products. In this sense, the use of biodegradable plastics is a more than the satisfactory alternative. However, in order to grow their performance, they constantly need to be improved, so composite materials based on biodegradable or recyclable polymers have started to be used frequently as a viable alternative. The present manuscript reveals the mechanical behavior of such composite material obtained by coating Arboblend V2 Nature granules with silver nanoparticles (AgNPs). The coating is intended to improve the antibacterial activity of the base material. The obtained results underlined the fact that with the incorporation of AgNPs in the polymer mass, the mechanical performances (tensile strength, bending strength, elongation, modulus of elasticity) of the material decrease visibly. Thus, the possibility of use of the parts in applications that involve exposure to pulling or bending is quite low, but can successfully replace other biodegradable/non-biodegradable polymeric materials that have metal particles in their structure and which do not present antibacterial action.
Key words: biodegradable thermoplastic, mechanical characterisation, PVD, AgNPs.

1. INTRODUCTION

This study is set to explore the potential advantages of combining a biopolymer named Arboblend V2 Nature with silver nanoparticles. Silver nanoparticles are known to provide antimicrobial properties for surfaces. Antibacterial activity of silver nanoparticles has been of much interest over the past decade, and silver has been incorporated into different products for antibacterial effect. Silver plating is one of the earliest electroplating processes. Silver plating has been conventionally used in the olden days for the aesthetic purpose of improving the appearance of metals. Further, metal finishing has got importance in engineering. It is now extensively used for various applications such as low-end printed-circuit boards (PCB), computer chips, and ICs in the microelectronics industry, self-lubricating coatings used at extreme temperatures in the aerospace industry, etc. The continuous efforts and the theoretical understanding of the electrochemical engineering principles accelerate electrochemical technology in the aerospace industry [1-3]. Physical Vapor Deposition (PVD) represents one of the most used coating methods in the industrial sector. Creating PVD coatings on non-metal materials is an unconventional approach, which is not very investigated. The PVD process is based on releasing coated material from the source target and transferring it to the coated object surface, thus creating a thin film. The technique consists in evaporation and condensation of a material to produce a thin film over a substrate (object). The most common PVD processes are sputtering and evaporation. PVD can be adapted to requests, and the layers can be improved for various features, like decorative, optical, electrical, and mechanical properties, [4-6].
The manuscript aims to evaluate the obtained mechanical characteristics of a biodegradable material - Arboblend V2 Nature (granules - substrate) and silver nanoparticles –AgNPs (coating material) through Physical Vapor Deposition (PVD) process. Arboblend V2 Nature is a thermoplastic material made from by-products of the wood pulp industry able to replace plastic materials made from petroleum, [7-9]. Silver nanoparticles are known to provide antimicrobial properties for surfaces. Physical Vapor Deposition is one of the most used coating methods in the industrial sector. The main goal was to create samples of the new material – a reinforced one, that can be further exploited in an extensive variation of applications in areas such as

medical, dental, automotive, electronics, and others. Since the injected samples from the granules coated with AgNPs showed structural, morphological, thermal and antibacterial characteristics according to some studies, [10-12], it was wanted to experimentally determine the mechanical behavior of the samples by using two classical, test methods, tensile test and bending test, to see the influence of AgNPs incorporating into the polymer structure.

2. MATERIALS AND METHODS

The polymer selected as substrate for coating with silver nanoparticles was Arboblend V2 Nature. This thermoplastic according to the scientific literature, [7-9], contains - depending on the application - various biopolymers such as, for example, polyhydroxyalkanoates, polyesters, Ingeo TM, lignin, starch, natural resins or waxes, organic additives, cellulose, natural reinforcing fibers. It is mainly made from renewable resources. Arboblend granules has a high biodegradation degree and has properties comparable to conventional plastics, [7-10].
Tensile test: The injection of the Arboblend V2 Nature + AgNP's biodegradable composite material was performed according to the experimental factorial research plan, using the ANOVA method, and the Minitab 17 program. The samples are "dog bone" shaped and dimensioned according to ISO 527: 2, [13]. The experiments were performed according to a complete factorial program of type 2^3 (8 experiments), in which the factors were the injection temperature - T_{top} [ºC], the injection pressure - P_{inj} [MPa] and the cooling time – t_r [s]. For each experiment, three samples were used to highlight the stability of the process by calculating the average and dispersion of the values for each set of values of the input parameters in the experimental plan. Each test generated responses on tensile strength, σ [MPa], elongation, ε [mm] and modulus of elasticity, E [MPa] of the analysed biodegradable material, calculating for each the average and dispersion.
Bending tests: For the bending tests performed, a three-point loading system was used, using INSTRON 5587 - equipment adapted for bending testing. The dimensions of the tested samples were in accordance with the ISO 178:2019 standard, [14], 80mm long, 10mm wide and 4mm thick, the test was at the time of complete failure of the sample. The test consisted of positioning a sample with a rectangular cross section 10x4.2 [mm] on two parallel support supports Φ = 10 mm placed at 60 mm from each other. The loading force is applied to the middle of the distance between the support rollers, the sample being placed on the side of 10 [mm]. Bending tests were performed at room temperature. The loading forces were greatly reduced.

3. RESULTS AND DISCUSSION

3.1 Tensile test

Following the experimental results, it was observed that the best results, the highest values of tensile strength, σ_{max}, were recorded in the experiment with number 1, (12.60 ± 1.73) MPa (Figure 1). The values obtained are influenced by the values of the process parameters used: injection temperature - 155°C, injection pressure - 80MPa and cooling time - 15s. The process parameter that seems to have a significant influence on the recorded results is the injection temperature.

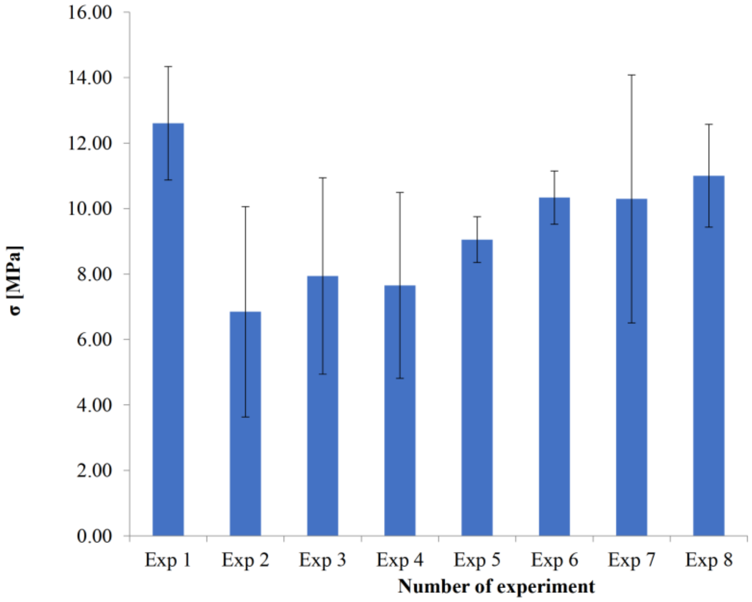

Fig. 1. Tensile strength of the tested samples

Analyzing the standard deviation of the results, from the best experiment according to the value recorded for tensile strength it can be concluded that the material Arboblend V2 Nature + AgNPs recorded a low dispersion of results, Figure 1.
However, we cannot discuss about an improvement in tensile strength by incorporating AgNPs, but rather a drastic decrease in it. According to the specialized literature, the Arboblend V2 Nature material, in the same test conditions registers a tensile strength of (44.05±0.48) MPa, [9]. This decrease is attributed to AgNPs which, instead of forming chemical bonds with the polymeric mass, on the contrary broke the existing ones and caused decrease of mechanical performance.
In the case of elongation, ε, it denotes due to very low values that the rupture was sudden and the behavior of the material is fragile, Figure 2. Its fragility was given by the incorporation of the nanoparticles layer from the surface of the granules in the biopolymeric structure. The effect of embedding was negative also in terms of elongation, because silver nanoparticles created discontinuities in the polymeric structure that led to the easy release of the material under the action of progressive loads. The substrate usually records value of tensile strain at fracture of 4.88±0.3%, [9].
Analyzing the data available in Figure 2, it can be noted again that experiment number 1 shows the highest values of elongation, (1.31±0.57) mm but with a large standard deviation, which means that the analyzed samples had discontinuities, which led to different breaking of the tested samples.
The modulus of elasticity values, E, are quite similar highlighting the same rigid behavior of the material, Figure 3.

3.2 Bending test

Figures 4, 5 and 6 show the values of the parameters of output, displacement, bending strength and elasticity mode for all eight experiments performed.
Due to the incorporation of nanoparticles in the biopolymer structure of Arboblend V2 Nature, the behavior of the material became rigid, an aspect highlighted by the bending strength and displacement of the tested samples, Figure 4 and Figure 5.
The best results of bending strength and displacement were recorded in the experiment with number 8, 32.95 ± 0.48MPa and 4.37 ± 0.19mm. Another experiment with results close to this was experiment number 4, of being lower by only 2MPa. The values of these output parameters were influenced by the injection parameters, namely the injection pressure at the second variation level, 100MPa and the cooling time 30s. The higher pressure helped to better compact the biopolymer in the injection mold and the longer cooling time allowed for closer intermolecular bonds.
The structural homogeneity of the samples and the experimental reproducibility is highlighted by the low values of standard deviation obtained for each experiment aspect visible in Figures (4-6).
According to the literature, [8], the maximum arrow in case of the Arboblend V2 nature is 5.44 mm.

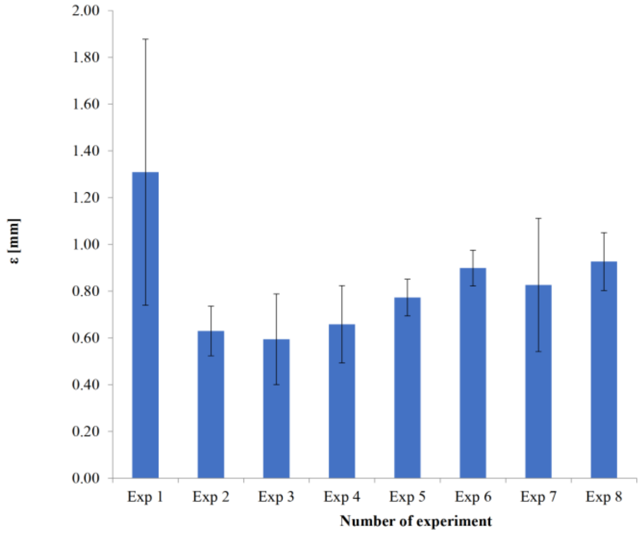

Fig. 2. Elongation of the analysed samples

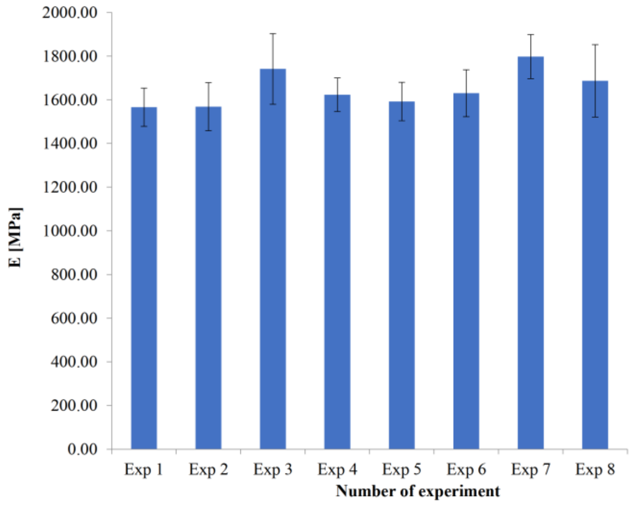

Fig. 3. Young's modulus of the tested samples

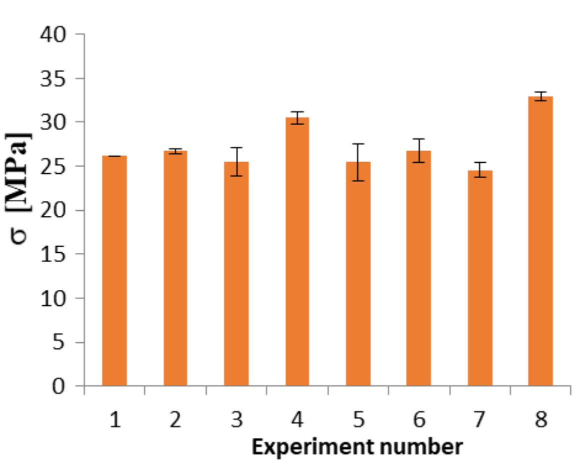

Fig. 4. Variation of bending strength depending on process parameters

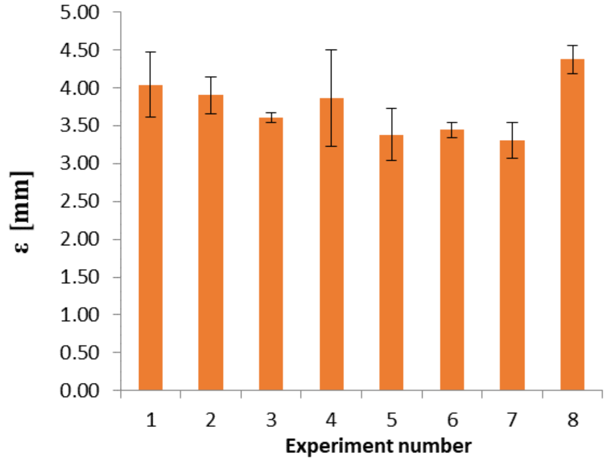

Fig. 5. Displacements recorded in the case of the 8 experiments of the complete factorial plan

In case of Young's modulus the results for the eight experiments are quite compact. The highest standard deviation is recorded by experiment 4, as an effect of the technological parameters, which acted in reverse.

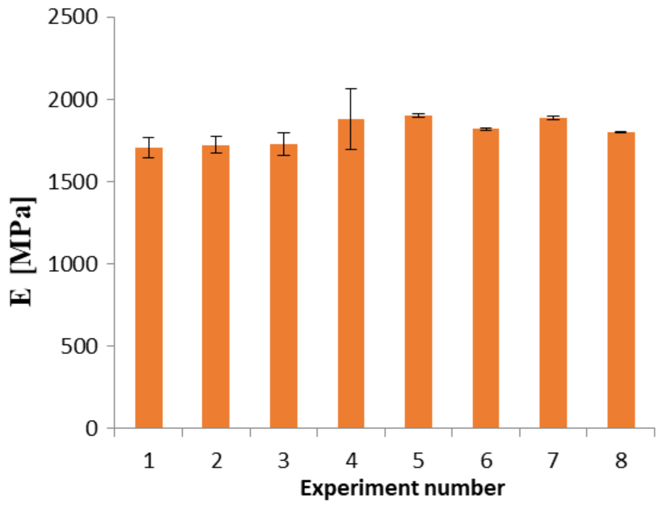

Fig. 6. Variation of modulus of elasticity during variation of injection parameters

4. CONCLUSIONS

The obtained composite material Arboblend V2 Nature + AgNPs following the mechanical tests on tensile and bending, emphasized the following behaviour:
- the values of tensile strength decreased by incorporation of AgNPs by up to 3.5 times compared to the base material, due to the discontinuities created by these ones in the polymer structure;
- in terms of bending testing, it also recorded lower values than the base material with 24.5%, the reason being of course the same, the presence in the structure of silver nanoparticles;
- the standard deviations of the average values presented for each experiment, still, highlighted the uniform distribution of AgNPs in the polymer mass, as their values are quite low in the case of all the highlighted parameters;
- the tested samples withstand transverse stresses better than longitudinal stresses.

The possibility of substituting polymers based on fossil resources is not the purpose of this type of mechanical test, but the Arboblend V2 Nature + AgNPs composite material can replace from this point of view other biodegradable plastics (based on renewable resources) which do not have antimicrobial characteristics like this one, [10].

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