



## ASSESSMENT OF DEGRADABLE AND MECHANICAL PROPERTIES OF NANO-CONTAINING WOUND HEALING POLYMER MATERIALS

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**Цель.** Оценить механические и деградирующие свойства наносодержащих ранозаживляющих полимерных материалов в исследовании *in vitro*.

**Материал и методы.** Для исследования использовались биополимерные основы в виде пленок, в которые вводили наноксид цинка (ZnO), наноксид магния (MgO) и наноксид кремния (SiO<sub>2</sub>) в различных концентрациях. В условиях *in vitro* изучали деградацию, относительное удлинение при разрыве, прочность при разрыве на разрывной машине, плотность и твердость по Шору, а также набухающие свойства исследуемых биополимеров.

**Результаты.** Исследование показало, что введение в полимерную основу 1%-го оксида кремния несколько увеличивает прочность пленки при разрыве, в то время как увеличение его содержания до 5% несколько уменьшает ее. Такая же закономерность наблюдалась и в случаях введения в пленки наноксидов цинка и магния. Через одни сутки выдержки пленок в воде прочность при разрыве не удалось установить, так пленки деградировали и разрушались при закреплении исследуемых образцов в разрывной машине. Это свидетельствует о способности пленки деградировать, находясь в контакте с жидкостью. Проведение исследования при 36°C показывает, что прочность всех пленок резко снижается и находится в пределах погрешности разрывной машины. Исследование плотности синтезированных пленок показало, что пленки с 1% содержанием наноксидов цинка и оксида кремния имеют высокую плотность, что коррелирует с прочностью при разрыве. Определение степени набухания пленок показало высокую способность к набуханию пленок без наноксида цинка и несколько уменьшенную степень набухания в присутствии наноксида цинка.

**Заключение.** Проведенные нами исследования показали, что свойства биodeградирующих полимерных материалов зависят от концентрации действующих лекарственных средств, которые в них введены, а наличие у них свойства деградации может обеспечить дозированную доставку лекарственного средства в область поражения.

*Ключевые слова:* раны, лечение ран, раневые покрытия, наносодержащие материалы, деградирующие полимерные материалы

**Objectives.** To evaluate the mechanical and degrading properties of nano-containing wound-healing polymer materials in the study *in vitro*.

**Methods.** The bio-polymer bases in the form of films were used in the research in which nano-oxides zinc (ZnO), magnesium nano-oxides (MgO) and pyrogenic silica (SiO<sub>2</sub>) in various concentrations were introduced. The degradation, relative elongation at break, tensile strength in tensile testing machine, density and Shore hardness, and their swelling properties of the studied bio-polymers were investigated *in vitro*.

**Results.** The study has shown that the introduction into the polymeric base of 1% solution of silicon oxide slightly increases the film strength, while an increase in its content up to 5% slightly reduces it. The same pattern is observed in the case of the introduction of zinc and magnesium into the film. After 1 day of the film exposure in water, tensile strength could not be determined as the films degraded and was destroyed while fixing the studied materials in the tensile machine. This demonstrates the ability of the film to degrade being in contact with the liquid. Conducted at 36°C study shows that the strength of all films is sharply reduced and is within the error of the tensile machine. Investigation of the density of synthesized films has shown that films with 1% content of zinc nanooxides and silicon oxide have a high density, which correlates with the breaking strength. Determining the degree of film swelling has shown a high capacity for swelling in the films without nanooxides of zinc and somewhat decreased degree of swelling in case of its presence.

**Conclusions.** Our study has shown that the properties of bio-degradable polymeric materials depend on concentration of active drugs that are introduced and their degradation properties can provide drug delivery of the medication to the affected region.

*Keywords:* wounds, treatment of wounds, wound coverings, nano-containing materials, degradable polymer materials

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Assessment of Degradable and Mechanical Properties of Nano-Containing Wound Healing Polymer Materials

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## Introduction

Wounds and related complications tend to increase in number. It should be noted that effective treatment of wound infections is crucial for a patient [1].

Nowadays, various methods and tools are applied for the wounds treatment [2]. One of such promising methods of wounds healing, preventing infections and their complications is developing new polymers with biodegradable properties [3].

Such materials must be biocompatible, non-toxic and degrade gradually with the ability to deliver a therapeutic agent [4].

The most effective ones are biologically active wound healing coatings that have all the necessary properties for normal wound healing process taking into account a stage, with additional therapeutic effect due to the medications they contain [5, 6].

Currently, broad-spectrum antiseptics are used increasingly for pathogenic microorganisms' termination in the wound [7].

The polymer systems with controlled release of bioactive substances are composed of polymer carrier and of an active ingredient which form a complex possessing a certain physiological activity and variable pharmacokinetics. While developing polymer systems with bioactive substance, mainly with drugs, the choice of polymer is determined not only by such its properties as biocompatibility, ability to biodegradation, molecular weight, molecular weight distribution, physical and mechanical properties, porosity, viscosity, etc., but also its ability to implement a mechanism of drugs controlled release within the optimal period of time. The materials intended for the wounds treatment, must meet many requirements and, besides, must have optimal biodegradation period [8].

In polymer systems with controlled diffusion, a drug does not form a chemical bond with the polymer; its release occurs either due to diffusion through the polymer membrane or due to polymer degradation [9].

The objective of the study was to evaluate the mechanical and degradable properties of nano-containing wound healing polymer materials during the *in vitro* experiment.

## Methods

The developed biodegradable polymer base "Biodep" [10], which contains gelatin, polyvinyl alcohol and lactic acid cross-linked under the influence of microwave irradiation with glycerol added as a plasticizer.

Biopolymer bases containing zinc nano-oxide (ZnO), magnesium nano-oxide (MgO)

and the pyrogenic silica oxide (SiO<sub>2</sub>) in different concentrations were used for the study.

The samples used for the study were made in the form of the film and were marked according to their composition in the following sequence: 1 – polymer base (control); 2 – polymer base with 1% of pyrogenic silica; 3 – polymer base with 5% of pyrogenic silicon oxide; 4 – base polymer with 1% of nanoscale zinc oxide; 5 – polymer base with 5% of nano-oxide nanoscale zinc; 6 – polymer base with 1% of nanoscale magnesium oxide; 7 – polymer base with a 5% of nanoscale magnesium oxide.

The tests were conducted at temperature 18°C and 36°C and at the relative humidity 78-80%. The samples were studied, provided they stay in the air and in distilled water within 1 hour and 24 hours' time intervals, respectively.

Under *in vitro* conditions, degradation, breaking elongation (All Union State Standard – 14236-81), breaking strength (All Union State Standard – 14236-81) on the tensile machine of FPZ-10/1 type, density (All Union State Standard 15139-69) and Shore hardness (All Union State Standard 24621-91) were studied in the "Laboratory of certification testing of anticorrosive insulation pipelines testing" at "Institute of Physics and Mechanics named after G.V. Karpenko" of the National Academy of Sciences of Ukraine.

The swelling rating study of the designed samples was performed in the laboratory at the Chair of Biological and Medical Chemistry of SHEE "Ivano-Frankivsk National Medical University".

The swelling rating study of the designed samples was performed according to the practical standard, up to which samples were weighed on the electronic scales AD200 (weighing error 0,001-0,003 g), and submerged at temperature 18°C and 36°C. Samples were picked up from water, their surface was wiped with filter paper to remove the water excess one hour after, 24 hours and 48 hours afterwards.

The swelling rating was calculated according to the formula:

$$\alpha = \frac{m_1 - m_0}{m_0} \cdot 100\%$$

where, – swelling rating;  $m_1$  – sample weight after submerging;  $m_0$  – sample weight before submerging.

All studies were performed three times, with defining the mean values and with processing statistical data which were registered in the table. Parametric descriptive statistics was used, and license packages for statistical analysis of Microsoft

Table 1

Mechanical Strength Testing (M±m)							
Characteristics sample, MPa	Sample Tests Results,						
	1	2	3	4	5	6	7
Breaking strength	4.8±0.25	5.10±0.49	2.50±0.31	2.40±0.34	1.10±0.03	3.0±0.10	1.4±0.07
Breaking strength after submerging for 1 hour, at t 18°C	1.8±0.10	2.20±0.06	0.4±0.01	0.5±0.01	0.1±0.01	0.9±0.04	0.2±0.01
Breaking strength after submerging for 1 hour, at t 36°C	Sample ruined during the test	0.08±0.002	0.093±0.011	0.09±0.003	0.04±0.003	0.05±0.002	0.04±0.001
Breaking strength after submerging for 24 hours, at t 18°C	Samples ruined during the test						
Breaking strength after submerging for 24 hours, at t 36°C	Samples ruined during the test						

Excel were used. The data are presented as an average and standard error (M±m). Differences were assessed with the help of Student’s t-test and accepted them as reliable at p<0.05.

**Results**

The analysis of the breaking strength (Table 1) reveals that the introduction of 1% silicon oxide into the film polymer basis, makes it slightly stronger whereas increasing silicon oxide content up to 5%, somewhat reduces film strength. The same pattern was observed in cases of zinc nano-oxide and magnesium adding into the film. After sample submerging for 1 hour at temperature 18°C, its breaking strength decreased about twice. The research conducted at temperature 36°C shows that the film breaking strength decreases rapidly and remains within the error of the tensile machine. After film submerging for 24 hours, its breaking strength could not be defined, since the film degraded and were destroyed when the studied samples were being fixed in the tensile machine. This proves the film ability to degrade under the contact with the liquid.

Breaking elongation study (Table 2) shows that the films have a relatively high percentage of elongation of the polymer base that is reduced after adding 1% of silicon oxide and increases with

its contents decreasing. Zinc nano-oxide makes breaking elongation relatively higher than it is in the base film regardless of its containing percentage. At the same time, the presence of magnesium nano-oxide makes samples breaking elongation lower. After the film submerging for 1 hour at t 18°C, its breaking elongation decreases about 3 times. While submerging the film for 1 hour at t 36°C, this characteristic slightly increases. It appeared impossible to measure the relative elongation after 1 day because of the polymer ability to degrade after a long contact with water.

Studies of the synthesized films density proved it to be within the range of 1.5 ±0.05 (M±m) (Table 3), but the film containing 1% of zinc nano-oxide content demonstrated high (1.78 g/cm<sup>3</sup>) and silicon oxide (1.42 g/cm<sup>3</sup>) density, which correlates with the breaking strength. Shore hardness research in conventional units (c.u.) revealed greater hardness in the sample with magnesium nano-oxide than with other medications, showing its inverse relationship with strength while breaking.

Findings analysis shows that film strength provided its sufficient level of strength is greatly affected by absorbed water, which makes the film structure less stable, and which in its turn results in degradation.

Films swelling rating of the most promising films proved to be higher in the samples without

Table 2

Breaking elongation							
Characteristics, %	Sample Tests Results,						
	1	2	3	4	5	6	7
Breaking elongation, %	78	60	100	83	82	60	63
Breaking elongation after submerging for 1 hour, at t 18°C, %	20	17	30	25	24	19	12
Breaking elongation after submerging for 1 hour, at t 36°C, %	Samples ruined during the test	41	50	28	32	22	37
Breaking elongation after submerging for 24 hours, at t 18°C, %	Samples ruined during the test						
Breaking elongation after submerging for 24 hours, at t 36°C, %	Samples ruined during the test						

Table 3

Characteristics	Density and hardness of synthesized films (M±m)						
	Test Results						
	1	2	3	4	5	6	7
Density, g/cm <sup>3</sup>	1.03±0.01	1.42±0.05	1.02±0.01	1.78±0.04	1.05±0.02	1.16±0.08	1.01±0.01
Shore hardness (c.u.)	78±0.10	54±0.05	76±0.06	72±0.03	82±0.23	86±0.30	96±0.30

Table 4

Sample	Films swelling rating study						
	Test Results						
	Weight, g	Weight, g in 1 hour	Swellingrating, %	Weight, g in 24 hours	Swellingrating, %	Weight, g in 48 hours	Swellingrating, %
1	0.28±0.01	1.101±0.03	293.2	1.488±0.01	431.4	0.92±0.04	228.6
4	0.57±0.02	1.650±0.03	189.5	2.3±0.01	303.5	2.15±0.03	277.2
5	0.75±0.04	2.2±0.02	283.3	2.98±0.05	297.3	2.23±0.1	197.3

zinc nano-oxide and it was slightly reduced in the samples containing it (Table 4). At the same time, swelling rating of the films without the active ingredient started to decline after 2 days, but it was greater in the presence of zinc nano-oxide.

### Discussion

Thus, it was found out that the mechanical stability of the polymer films meets the requirements for their application and depends on the concentration of the medication it contains. The water impact on these properties further confirms that these films gradually degrade under the influence of fluid and can be used as a means of drug delivery in the wounds treatment. Confirmation of such dependence of degrading and mechanical properties of polymer films depending on their content is discussed in some experimental studies [5].

Some scientific studies confirm our results concerning swelling of the tested material. Adding some nano-composite materials into the film base directly affects the physical and chemical properties of polymer materials [11, 12].

### Conclusions

1. The developed biodegradable polymer materials have sufficient flexible and mechanical properties for their application in the wounds treatment.

2. Mechanical and degradable polymer properties depend on the concentration of the active medications they contain.

3. The synthesized polymeric material gradually degrades under fluid impact and it can provide drug dosage delivery into the area of injury.

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