

Nataliya Semenyuk, Ulyana Kostiv, Oleg Suberlyak and Volodymyr Skorokhoda

PECULIARITIES OF FILLED POROUS HYDROGELS PRODUCTION AND PROPERTIES

*Lviv Polytechnic National University 12, Bandera str., 79013 Lviv, Ukraine
vskorohoda@yahoo.com*

Received: September 26, 2012 / Revised: October 16, 2012 / Accepted: December 20, 2012

© Semenyuk N., Kostiv U., Suberlyak O., Skorokhoda V., 2013

Abstract. The peculiarities of porous hydrogel compositions formed on the basis of copolymers of methacrylic esters and polyvinylpyrrolidone with mineral and organic filler have been investigated. In the composite structure silver particles are obtained *via* argentum nitrate reduction by tertiary nitrogen of polyvinylpyrrolidone. The effect of filler nature and amount, argentums nitrate amount and composition of polymer-monomer mixtures on the polymerization rate and properties of composites has been examined.

Key words: hydrogel, polyvinylpyrrolidone, argentums nitrate, filler, polymerization rate.

1. Introduction

The development of new osteoplastic materials capable to stimulate the regeneration of bone tissue is of special attention for modern renewal surgical operations, in orthopedy and jaw-facial surgery, in particular. Different domestic and foreign preparations are used. They are produced on the basis of non-organic matrix of cattle natural bone tissue (hydroxyapatite and tricalciumphosphate) which contains chemical elements in the same form as in vital organism. But in connection with the increasing numbers of animals diseases the developed countries show interest in synthetic preparations [1]. On the other hand, if the materials are produced from hydroxyapatite, they are brittle and their strength characteristics are inferior to bone properties. The application of porous polymer-mineral composites based on calcium-phosphate materials (which are similar to bone by their composition) and biocompatible polymeric matrix, namely on the basis of 2-hydroxyethyl-methacrylate (HEMA) and glycidylmethacrylate (GMA) with polyvinylpyrrolidone (PVP) copolymers allows to combine their advantages and get out of disadvantages.

However long or even lifelong being of the composites in the human or animal organisms is very often accompanied by inflammation or rejection and requires the constant introduction of preparations (including antibiotics) into the organism. The decision of this problem may be partially solved by using the composites with micro-, nano- or colloid silver particles as the materials with antibacterial and antiseptic properties [2]. Therefore it is necessary to introduce argentums salts into the initial compositions. The salts interact with PVP polymeric matrix containing tertiary nitrogen and allow to obtain silver nanoparticles directly during composite formation without additional toxic reducing agents.

The aim of the present work is to develop new compositions with antiseptic and antibacterial properties based on (co)polymers HEMA with PVP capable being applied in medicine (in osteogenesis) and to investigate the effect of composition structure on the regulations of composites formation and properties.

2. Experimental

HEMA of Bisomer trade (residual pressure of 130 N/m^2 , $T_{boil} = 351 \text{ K}$) and GMA (residual pressure of 520 N/m^2 , $T_{boil} = 342 \text{ K}$) were purified *via* vacuum distillation. The molecular mass of highly purified PVP of AppliChem CmbH trade was $28 \cdot 10^3$. PEG-1500 polyethyleneglycol was used for the foam stabilization. Argentum nitrate was of analytical pure grade. Hydroxyapatite (HA) $\text{Ca}_{10-x}(\text{PO}_4)_6(\text{OH})_2$ with the particles size of 0.05–1.25 mm was synthesized at the Department of Silicates Technology of Lviv Polytechnic National University. Copolymers were obtained *via* block-copolymerization under previously determined conditions [3]. The polymerization kinetics was studied by determination of non-reacted HEMA and GMA amount in the composition [4]. The average diameter of pores (d_n) and polydispersivity index (PDI) were determined by size measuring of at least 100 pores using MBS-9 microscope.

The total porosity and composites density were determined using a Manehold method described in [5]. The mechanical properties were studied in accordance with general standards.

3. Results and Discussion

The structure and properties of polymeric materials to a great extent are determined by synthesis conditions. To establish the synthesis regime of HEMA with PVP copolymers and to study the effect of filler and argentums salts on the mentioned parameters the polymerization kinetics was investigated. The calculated dependences of polymerization reduced rate for different compositions are represented in Figs. 1 and 2.

PVP effect on the character of kinetic curves is similar to the block and dispersive polymerization, as well as polymerization in solution – the increase in PVP amount increases the polymerization rate. At the same time the absence of inductive period while PVP addition to the composition should be noted. The reason is a matrix effect with complex formation and charge transfer between monomer and PVP components [6, 7].

To compare the reactivity of different methacrylic esters we studied the polymerization kinetics of PVP with HEMA and GMA compositions in the presence of HA with particles size of 0.1–0.2 mm. The polymerization rate of hydrophobic GMA at the initial stages is essentially higher (Fig. 1a) than that of HEMA. This fact is in a good agreement with kinetic investigations of dispersive polymerization of the same monomer-polymeric compositions [8] without a filler, but the essential disadvantage of such compositions is a sharp decrease of polymerization rate at the deep conversion.

HA amount also affects the polymerization proceeding. The compositions with HA in amount of 70 % mas have less reactivity compared with that of the compositions without the filler. After AgNO_3 addition the polymerization rate decreases, especially at the middle stages (Fig. 2, curve 2). The obtained results correlate with kinetic investigations of homogeneous polymerization in the block and in the HEMA-PVP composition solution in the presence of argentums salts [4], that is may be the result of radicals resonance stabilization over nitrate ions.

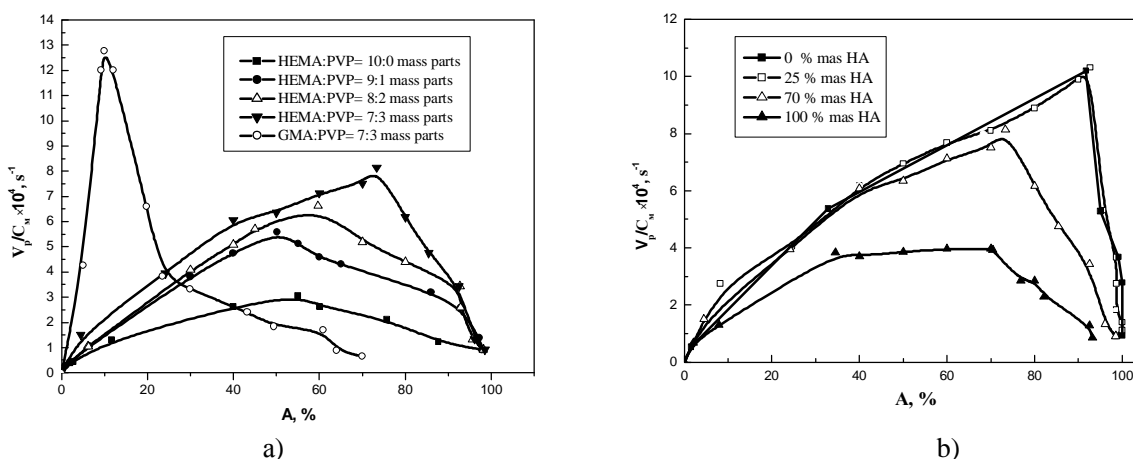


Fig. 1. Dependence of polymerization reduced rate upon the ratio monomer:PVP (a) and HA content (% relative to polymer-monomer composition mass) (b). HEMA:PVP = 7:3; $T = 348$ K; benzoyl peroxide concentration $[\text{BP}] = 1$ % mas

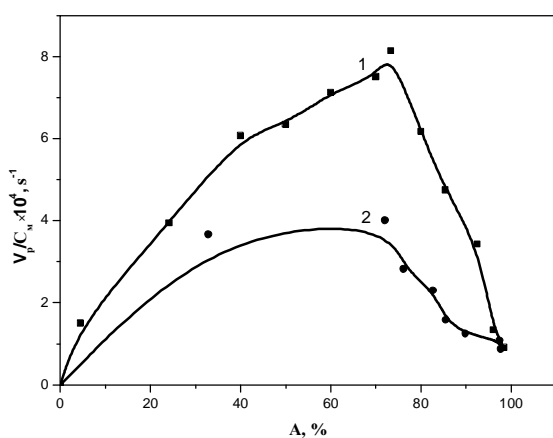


Fig. 2. Effect of argentums nitrate on the composition polymerization rate. $[\text{HEMA}:\text{PVP}:\text{PEG-1500}] = 7:3:2$ mass parts; $T = 348$ K; $[\text{BP}] = 1$ % mas; $[\text{HA}] = 70$ % mas relative to polymer-monomer composition; $[\text{AgNO}_3], \%$ mas: 0 (1) and 1.5 (2)

To impart antibacterial properties to the composites the silver nanoparticles are obtained during composite formation *via* the argentum nitrate reduction by tertiary nitrogen in the dark. The reaction completeness was estimated using the method described in [9]. During the synthesis composites with PVP and argentums salts change their color from weak-yellow to brown. It is also the indirect confirmation of silver nanoparticles formation while interaction between argentums nitrate and PVP tertiary nitrogen. This method has irrefutable advantages over other known methods when nanoparticles and hydrogels are prepared separately or when hydrogel is saturated with argentums salts or when silver nanoparticles are obtained *via* its reduction by amino-containing methacrylic monomer followed by its copolymerization with other monomers [2]. Moreover, there is no necessity in toxic amino-containing reducers.

One of the main bioplastics requirements is the presence of through porous structure with controlled micro- and macropores sizes necessary for implant composite growth by bone tissue. Therefore, at first we studied the effect of nature of potential pores forming agents on the porous structure formation and composites conditional density. The basic polymer-monomer composition was the composition [HEMA]:[PVP] = 7:3 (mass parts) with high reactivity and without demand of high curing temperature [6]. The pores forming agents were compounds of organic and inorganic nature: chloroform, methylene chloride, cyclopentane, hexane, calcium chloride, ammonium and potassium carbonate. The organic agents form pores at evaporation, calcium chloride – after its washing by water from a ready composite, ammonium and potassium carbonates – due to the decomposition and release of carbon dioxide at composite heating. The obtained results are represented in Table 1.

Porous material is not formed only in the case of hexane. Concerning the inorganic forming agents (calcium chloride and ammonium carbonate), the high-porous composites were obtained with fine pores, the size of which does not exceed 0.4 mm. While using organic

ones: chloroform, methylene chloride and cyclopentane the materials with satisfied size of pores (0.8–1.3 mm) are formed.

The value of porosity considerably depends on the components ratio. The proportional dependence of material porosity on PVP amount is observed (Table 2). Porosity increases from 37 % for polyHEMA to 67–70 % for copolymer HEMA-PVP with PVP content of 30 mas %. This fact reveals that PVP positively affects not only the kinetics of composite curing but pores forming as well. The addition of crosslinking agent – ethylene glycol dimethacrylate (EGDMA) – does not change the general porosity but increases compression strength by 50 %. It means that such mixtures may be effectively used because the material substituting the bone tissue undergoes considerable mechanical load. Argentum salts do not affect the general porosity, though the polydispersivity index increases with the increase of their amount.

The nature and amount of the filler also affects the composite formation and its properties (Table 3). Besides HA we used a haemochorial organic filler. Under observations of scientists from Lviv National Medical University such the filler accelerates the growth of bone tissue [10].

While curing the composition without HA the porous material is not formed even at the optimum amount of pores forming agent. To our mind, foaming takes place before the composition curing and kinetic investigations (see above) confirm this fact. At the same time in the investigated range the decrease of material porosity is observed with the increase of filler amount. The most homogeneous porous material with the least conditional density is formed with HA amount of 70 % mas. The partial exchange of HA for organic filler actually decreases the porosity and favors the formation of material with a wider distribution of pores by their sizes (PDI increases, see Table 3).

Besides HA amount, the sizes of its particles also influence the composite properties (Table 4).

Table 1

Effect of pores forming agent nature on the composites physical properties
(HEMA:PVP:PEG -1500= 7:3:2 mass parts, [HA]=70 mas %, [BP]=1 mas %, $T = 348$ K)

Pores forming agent	Amount of pores forming agent, mas %	Porosity, %	d_p , mm	PDI	Polymers conditional density, kg/m ³
Chloroform	18	42.5	0.79	2.69	1125
Methylene chloride	10	54.4	1.28	2.05	714
Cyclopentane	10	67.4	0.93	1.27	419
Hexane	10	Pores are not formed	–	–	–
Calcium chloride	5	66.5	0.29	1.71	1008
Ammonium carbonate	10	67.3	0.37	1.76	518
Potassium carbonate	0.5	61.0	0.53	1.37	639

Table 2

Effect of PVP amount and crosslinking agent EGDMA on the composite properties
 ([PEG-1500] = 20 mass parts, [HA]=70 % mas, cyclopentane is pores forming agent (10 % mas), [BP]=1 % mas,
 $T = 348 \text{ K}$)

	Structure of polymer-monomer composition, mass parts			Porosity, %	d_p , mm	PDI	Relative compression strength boundary (σ), MPa
	HEMA	PVP	EGDMA				
	10	0	–	37.3	1.75	1.70	10
	9	1	–	44.3	1.26	1.35	9.2
	8	2	–	53.0	1.12	1.89	9.1
	7	3	–	67.4	0.93	1.27	10.3
	7	3	10	70.3	1.81	1.38	15.5
*	7	3	–	66.4	1.58	1.32	–
**	7	3	–	66.7	1.50	1.45	–

The composition contains additionally: * – 1.2 mas % of AgNO_3 ; ** – 1.5 mas % of AgNO_3

Table 3

Effect of filler amount on the composite properties

HA amount, mas %	Organic filler amount, mas %	Porosity, %	d_p , mm	PDI	Composite conditional density, kg/m^3	Relative compression strength boundary (σ), MPa
0	0	Pores are not formed	–	–	–	8.6
25	0	90.1	1.19	1.99	990	9.9
50	0	80.4	1.20	1.98	611	10.1
70	0	67.4	0.94	1.27	419	10.3
100	0	67.3	1.41	1.76	553	10.1
150	0	38.9	0.46	1.69	1106	9.4
65	5	51.6	1.12	1.64	636	–
60	10	54.8	1.27	1.76	587	–
50	20	57.9	0.82	2.33	708	–
35	35	60.1	1.21	1.95	718	–

Table 4

Effect of hydroxyapatite particles size on the composite properties
 (HEMA:PVP:PEG-1500 = 7:3:2 mass parts; [HA] = 70 mas %)

Size of HA particles, mm	Porosity, %	d_p , mm	PDI	Conditional density, kg/m^3	Effective density, kg/m^3
< 0.10	57.6	1.39	1.41	770	1815
0.10–0.20	67.0	0.87	1.32	678	2056
0.32–0.40	59.2	1.40	1.85	738	1810
0.63–1.00	57.3	1.39	1.67	850	1994
1.00–1.18	40.4	1.56	2.46	941	1580

The increase of particles size by more than 0.1 mm decreases the total porosity of compositions and increases the copolymers conditional density. Using HA with the particles less than 0.1 mm, macropores of greater size are formed but the total porosity is lower. To our mind, the

reason is the agglomeration of filler fine particles during the composite preparation.

Photographs of the composites filled with HA are represented in Fig. 3. They confirm the presence of developed micro- and macroporous structure favoring the effective growth of the composite by bone tissue.

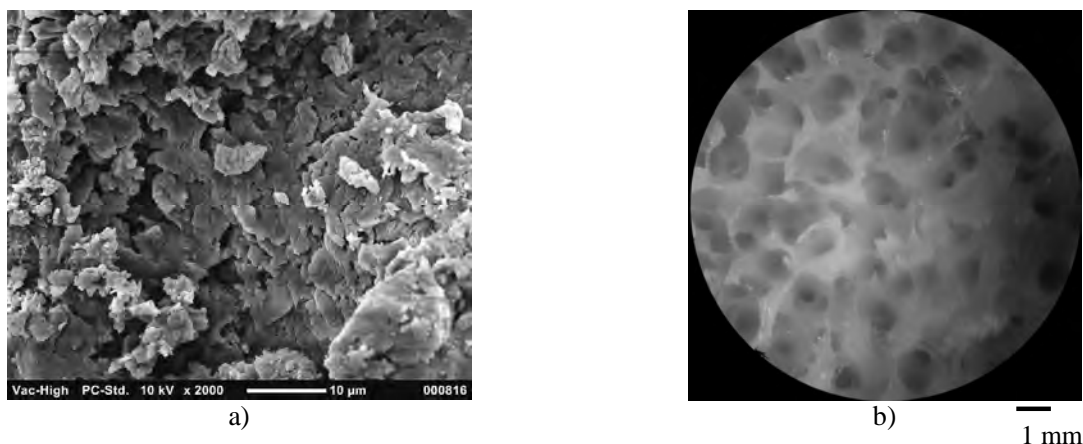


Fig. 3. Photographs of micro- (a) and macroporous (b) structure of HEMA-PVP composite filled with HA

4. Conclusions

Thus the effect of nature and ratio of the initial components on the properties of porous filled composites has been determined. These results will be used for optimization of composition structure of the material for osteogenesis and its further investigations including medical and biological ones.

References

- [1] Hasegawa S. and Tamura J.: *Int. J. Artif. Organs.*, 2005, **4**, 380.
- [2] Gres O., Lebedev E., Klymchuk V. *et al.*: *Ukr. Khim. Zh.*, 2009, **75**, 55.
- [3] Semenyuk N., Siryi O., Halyshyn O. *et al.*: *Visnyk Nats. Univ. Lvivska Politechnika*, 2010, **667**, 452.
- [4] Selyakova V. and Kashevarova Yu.: *Metody Analiza Acrylatov i Metakrilatov*. Khimiya, Moskva 1982.
- [5] Dubyaga V., Perepechkin L. and Katalevskiy E.: *Polimernye Membrany*. Khimiya, Moskva 1981.
- [6] Suberlyak O., Skorokhoda V. and Thir I.: *Vysokomol. Soed.*, 1989, **N5B**, 336.
- [7] Martins R., Quinell L., Souza G., Margues M.: *Chem. & Chem. Techn.*, 2012, **2**, 153.
- [8] Suberlyak O., Semenyuk N., Dudok G. and Skorokhoda V.: *Rus. J. of Appl. Chem.*, 2012, **85**, 830.
- [9] Pyatnitsky I. and Sukhan V.: *Analiticheskaya Khimiya Serebra*. Khimiya, Moskva 1975.
- [10] Got' I., Pogranichna Kh. and Siryi O.: *Exper. ta Klinichna Physiol. ta Biokhim.*, 2008, **4**, 48.

ЗАКОНОМІРНОСТІ ОДЕРЖАННЯ ТА ВЛАСТИВОСТІ НАПОВНЕНИХ ПОРИСТИХ ГІДРОГЕЛІВ

Анотація. Досліджено закономірності формування пористих композиційних гідрогелевих матеріалів на основі кополімерів метакрилових естерів з полівінілпіролідом з мінеральним та органічним наповнювачем. Показано можливість одержання в структурі композиту частинок срібла відновленням аргентуму нітрату третинним нітрогеном полівінілпіролідону. Встановлено вплив природи та кількості наповнювача, аргентуму нітрату, складу полімер-мономерної композиції на швидкість полімеризації та властивості композиційних матеріалів.

Ключові слова: гідрогель, полівінілпіролідон, аргентуму нітрат, наповнювач, швидкість полімеризації.