Synthesis, Purification and Modification of Poly(Methyl Methacrylate) Microspheres for Prosthetic Dental Applications

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Abstract: A large number of polymers are used for various applications in prosthodontics. Poly(methyl methacrylate) (PMMA) microspheres are commonly used for prosthetic dental applications, including the fabrication of artificial teeth, dentures, denture bases, obturators, orthodontic retainers, temporary or provisional crowns, and for the repair of dental prostheses. Obviously, one can find a lot of articles dedicated to PMMA synthesis. On the other hand, the materials used in prosthodontics are subject to very specific requirements. Thus, in this work, influence of all the stages of PMMA microspheres production (including synthesis and, especially, purification) on the polymers characteristics is detected.

Keywords: Poly(methyl methacrylate); microspheres; suspension polymerization; purification; modification.

INTRODUCTION

Poly(methyl methacrylate) (PMMA) microspheres are already used in many various fields of application, but its usage in clinical dentistry and surgery attracts highest attention [1]. PMMA microspheres are most commonly used in dental laboratories (to make orthodontic retainers and dentures and for repair), dental clinics (for relining dentures and temporary crowns), and industry (such as fabrication of artificial teeth) [2-4]. PMMA gained popularity for various dental applications due to its unique properties, including its low density, aesthetics, cost-effectiveness, ease of manipulation, and tailorable physical and mechanical properties [3, 5].

According to ISO 20795-1 2013 PMMA-based products can be divided into heat cured, cold cured, light cured and microwave-cured products. Regardless of the intended application, PMMA-based products are conventionally available in the form of a powder–liquid system. In most cases, the liquid component contains a monomer of methyl methacrylate (MMA) and cross-linking agents [5]. The powder contains a clear polymer (PMMA microspheres), polymerization initiator and various additives.

Obviously, exactly powder properties influence on the properties of the final product. Among all the PMMA powder properties the most valuable are: particles geometry and average size, concentration of initiator located inside PMMA pores, polymer purity (especially presence of salts) and molecular weight (in a lesser extend), copolymer composition (in case of copolymers usage). Thus, this work is dedicated to investigation of synthesis of PMMA with given characteristics for prosthetic dental applications. Moreover, influence of all technological stages of PMMA synthesis on polymer properties should be also detected.

EXPERIMENTAL

MMA (Sigma Aldrich) was used without any purification. Other reactants used had purity more than 96% (used without any purification).

Poly(2-acrylamido-2-methylpro-panesulfonic acid) (PolyAMPS) was synthesized according to the procedure [6].

PMMA was prepared by MMA suspension polymerization in water in the presence of a dibenzoyl peroxide initiator (BPO) and a dispersant according to the procedure [7]. The calculated amounts of distilled water and dispersant were loaded into the reactor, the contents of the reactor were mixed and heating was started. When 30–50°C was reached, a pre-prepared mixture of MMA with initiator was loaded and heating continued to 80°C. Weight ratio [H_2O] : [MMA] was equal to 3 : 1. The reaction mass was kept for 4 h at 80°C with stirring speed 140-1300 rpm (for various experiments). At the end of polymerization, the

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resulting polymer was washed with water and dried until its content did not exceed 0.5 wt %. The yield of PMMA was no less than 85 wt % in every experiment.

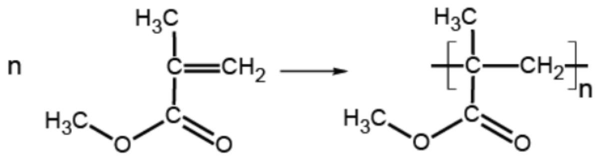
The surface view and particle size distribution of PMMA particles were determined using a C-2500 scanning microscope (Hitachi).

The average and number molecular weights of PMMA and PMMA microspheres were determined by gel permeation chromatography (GPC) with a UV detector (410 model refractive index). Samples were eluted with tetrahydrofuran through a linear ultrastryrogel column (10 and 100 Å pore size) at a flow rate of 1 ml/min at 30°C for 50 min. The molecular weight was determined relative to polystyrene standards using a millennium computer programme.

All the experiments were repeated at least twice. Relative deviations did not exceed ±5%.

RESULTS AND DISCUSSION

It is well-known, that PMMA properties and further application dramatically depend on MMA polymerization method (Scheme **1**). On the other hand, only PMMA microspheres may be used in prosthodontics. Thus, to begin with, the choice of adequate MMA polymerization method should be made. PMMA microspheres may be synthesized by emulsion polymerization [8] suspension polymerization [9, 10], dispersion polymerization [11], and seed polymerization [12]. Among all these methods suspension polymerization of MMA has a lot of advantages. For example, suspension polymerization offers facile heat dissipation and precise temperature control through an aqueous phase.



Scheme 1: Methylmethacrylate polymerization.

In general, MMA suspension polymerization process consists of several stages (Figure **1**). The first stage is preparation of organic phase (MMA and polymerization initiator) and aqueous phase (water, suspending agent or/and dispersant and stabilizer). The next stage is mixing of both phases in reactor and only then polymerization reaction begins. After synthesis reactor is cooled and separation of water phase and wet PMMA takes place. At this stage separation looks like decantation process, because it is needless to separate phases completely. Then wet PMMA should be washed with water (in some cases with acid or basic solutions) to remove residues of dispersant or stabilizer. In some cases the order of primary decantation and washing may be changed. After this, wet PMMA is filtered or centrifuged and then dried.

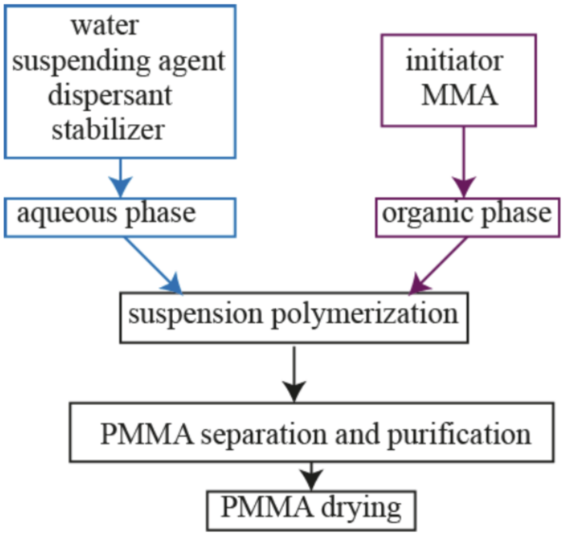


Figure 1: Typical MMA suspension polymerization process.

Particles Size

Influence of suspending agent type and stirring speed on average size of PMMA microspheres is shown in Table **1**. As it is seen, average diameter of PMMA particles dramatically decreases with the increasing of stirring speed. The same dependence can be observed while comparing the PMMA fractional composition (Figure **2**). Suspension polymerization of PMMA occurs in water-insoluble droplets. Increasing the mixing speed leads to greater destruction of these droplets and, consequently, to the cessation of the polymerization process and the formation of small particles of the product. Such well-known dependences take place no matter what type of suspending agent is used. The choice of suspending agent is determined by the availability of reagents, the required particle size and the availability of equipment for further neutralization and removal of suspending agent residues. In this work we use two suspending agents of principally different types to determine the general patterns of the technological process.

As it is seen from Table **1**, stirring speed and suspending agent type do not influence on PMMA molecular weight and M_W/M_N. In case of stirring speed

Table 1: Influence of Suspending Agent Type and Stirring Speed on Average Particle Size of PMMA. T=80°C; $C_{suspending\ Agent}$ = 0.5% W., $C_{initiator}$ = 2.2 % W

№	Suspending agent	Stirring speed, rpm	PMMA properties		average d, µm	References
			M_W·103	M_W/M_N		
1	Na-PolyAMPS	140	445	3,3	200	This work
2		340	387	3,7	92	This work
3		450	388	3,2	68	This work
4		800	391	3,2	54	This work
5		1300	383	3,2	16	Article 7
6	$Mg(OH)_2$	700	379	3,3	10	This work, Article 7
7		1000	385	3,4	2	This work
8		1300	382	3,2	1	This work

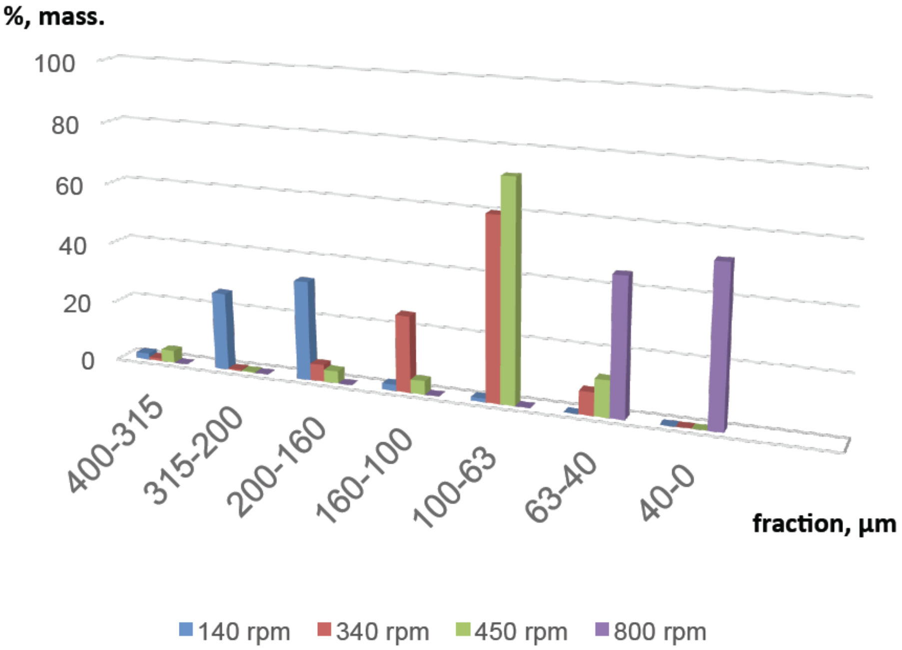


Figure 2: Influence of stirring speed on average particle size of PMMA. T=80°C; Suspending agent – Na-PolyAMPS; $C_{Suspending\ agent}$ = 0.5% w., $C_{initiator}$ = 2.2 % w.

below 150 rpm (Table **1**, line 1) PMMA molecular weight increases, what is fully explained by the change of hydrodynamic properties of the system under very low and insufficient mixing.

Polymer Purity

It was established that in order to obtain high-quality dental blanks, the initial polymer must contain minimal inclusions of impurities (since even small amounts of dispersant or other impurities sharply worsen the characteristics of polymer products). When obtaining dental polymers of proper quality, it is necessary not only to strictly control the initial raw material, but also to thoroughly wash the PMMA after synthesis. The visual differences between prostheses produced on the basis of pure and unwashed polymers are clearly demonstrated in Figure **3**.

One can see a significant difference in the prostheses shown in Figure **3**. A prosthesis based on pure PMMA (a) is characterized by a uniform surface, where the degree of coloring is directly proportional to the thickness of the layer. When using unwashed PMMA (b), particles of impurities remain on the surface of the prosthesis, which leads to the impossibility of uniform coloring and the appearance of spots of different shapes and colors on the surface of the prosthesis. Photos of washed and unwashed PMMA are presented in Figure **4**.

Figure 3: Prostheses produced on the basis of pure (**a**) and unwashed (**b**) PMMA.

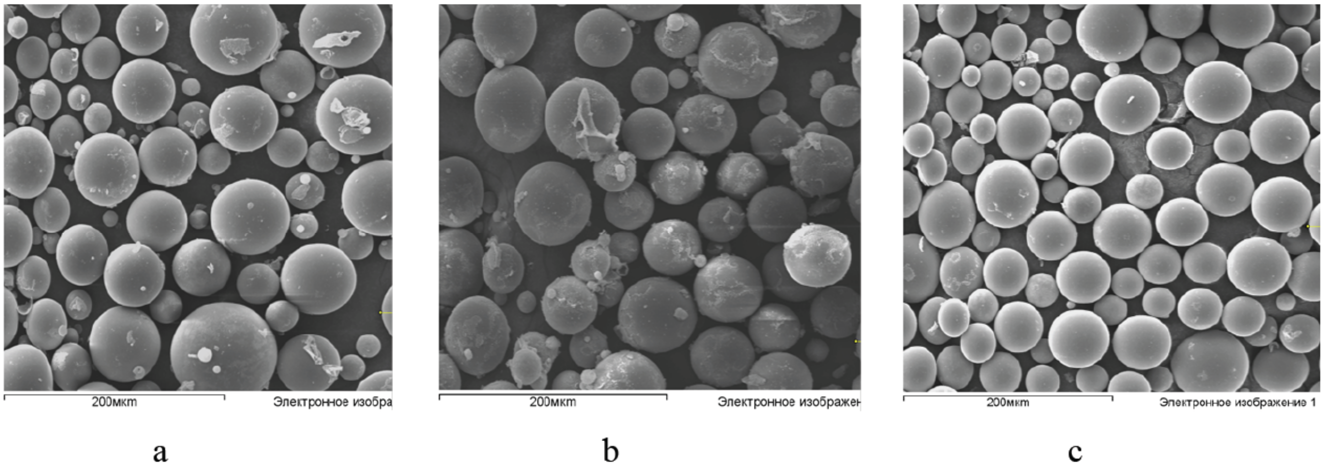


Figure 4: Photos of unwashed (**a**), washed 3 times (**b**) and washed 8 times (**c**) PMMA microspheres.

The cause of PMMA contamination is the presence of residues of the suspending agent or its neutralization products on its surface. Once again, we will consider two cases: using of Poly-AMPS or $Mg(OH)_2$ as suspending agents. In case of using Poly-AMPS or even partially neutralized Na-PolyAMPS neutralization of reaction mixture is made by basic solutions. In case of using $Mg(OH)_2$ – acidic solution is used (for example, sulfuric acid aqueous solution). In any case neutralization stage leads to the formation of salts contaminating the polymer surface. Thus, PMMA washing several times looks like the only way to clean the polymer.

There are some ways allowing to control polymer purity. It is known that the presence of salts leads to a change in the electrical conductivity of the system. It is proposed to use the electrical conductivity of the aqueous polymer extract as a criterion for its purity. Such a quick and simple analysis allows us to assess the degree of washing of the polymer and the need for additional purification. Moreover, one can determine the number of cycles sufficient to obtain a product of satisfactory quality. Example of experiment is presented in Table **2**.

Initiator Concentration in PMMA Microspheres

As it was written in Introduction section, PMMA microspheres using in prosthodontics should contain a certain amount of benzoyl peroxide (BPO) (from 0.2% in cold-cured PMMA up to 2.5% in bone cements). BPO can be mixed with dry PMMA mechanically after the synthesis or can be fixed in PMMA pores during the synthesis. Mixing PMMA with BPO requires specialized mixers and storage space, because BPO decomposes under the influence of light with formation of color pigmentation, what may be unacceptable in some cases. In this way, fixing certain amounts of BPO in PMMA pores during the synthesis looks rather

Table 2: Changes in Electrical Conductivity of Aqueous Pmma Extract Over 10 Cycles

Washing cycle	Electrical conductivity, μS/cm	Prostheses quality
1	152,9	-
2	144,2	-
3	131,1	-
4	119,2	-
5	99,6	+
6	76,5	+
7	58,3	+
8	29,3	+
9	27,9	+
10	17,9	+

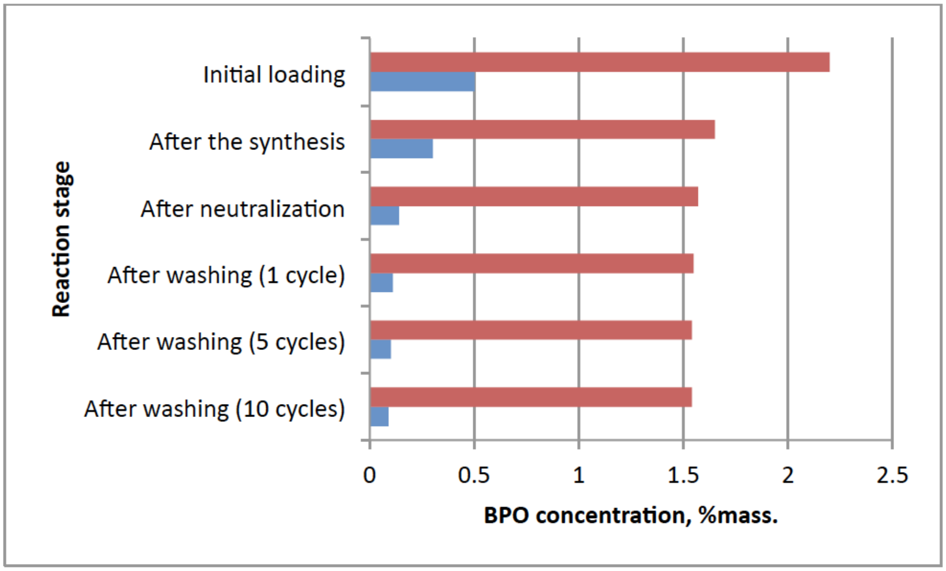


Figure 5: Loss of initiator during the PMMA synthesizes with various BPO initial loading.

attractive. Theoretically, amounts of BPO fixed in pores can be calculated based on the initial load of initiator or easily detected when conducting several experiments. On the other hand, some factors influencing the BPO concentration appear during the synthesis of pure PMMA microspheres. As it seen from Figure **5**, the main loss of the initiator occurs at the synthesis stage, what is explained by initiator participation in the reaction. At the same time, loss of the initiator occurs at further stages (especially during the neutralization stage). Obviously, formation of salts from acidic or basic dispersant by neutralization reaction is a rather exothermic process, which can activate decomposition of initiator. Loss of initiator during the washing stages looks rather negligible.

Perspectives of PMMA Microspheres Modification

In order to obtain good technological properties of the molding polymer mass from PMMA, the powders should have not only an optimal average size, but also the required "dough-forming" time (from mixing of powder and liquid phases to doughy stage) [5]. In some cases the required dough-forming time cannot be achieved by varying of PMMA average size, molecular weight or BPO concentration. Thus, PMMA needs modification, which can be produced by two chemical routes. In first case, the ester group of PMMA microspheres could be transferred to carboxyl or hydroxy group by hydrolysis or hydrogenation, respectively. Secondly, functionalized PMMA microspheres could be designed and fabricated through copolymerization between MMA and other monomers [13]. In authors opinion, the second route looks more attractive.

Thus, modification of PMMA was carried out by introducing small amounts of (co)monomers, such as ethyl acrylate (EA) and butyl methacrylate (BMA), into the polymer chain. Such modification should reduce the rigidity of PMMA macromolecules, as a result of which the polymer swells faster and dissolves more easily in the monomer. The obtained results are summarized in a graph in the form of a dependence of the influence of the additive concentration on the polymer dough-forming time (Figure **6**).

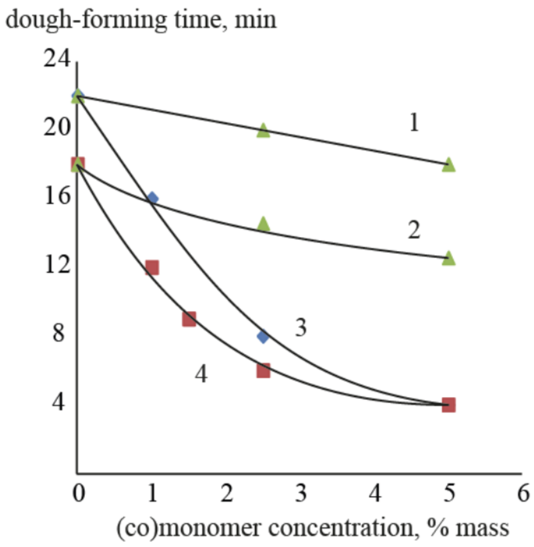


Figure 6: Influence of the (co)monomer (BMA – 1,2; EA – 3,4) concentration on the polymer dough-forming time.

Based on the obtained results, it follows that modification of PMMA is achieved by EA is more effective than modification by BMA. At the same time, using of EA has one big disadvantage. EA is a carcinogen and its vapors have a pungent smell. Thus, using of EA in production of medicine polymers seems rather questionable.

CONCLUSION

To sum it up, some details of synthesis and purification of Poly(methyl methacrylate) microspheres for prosthetic dental applications have been presented.

It is shown, that PMMA microspheres average size mostly depends on the stirring speed of the process. Loss of initiator absorbed in microspheres pores during all the technological stages of the synthesis is presented. It is shown that purity of PMMA can dramatically influence on prostheses quality.

Perspectives of PMMA modification to achieve microspheres with required dough-forming time are also presented. Further investigations will be dedicated to producing of PMMA microspheres for medical applications in industrial quantities.

CONFLICT OF INTEREST

There is no conflict of interests to declare.

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REFERENCES

[1] Sivakumar M, Panduranga Rao K. Synthesis and characterization of poly(methyl methacrylate) functional microspheres. Reactive and Functional Polymers 2000; 46(1): 29-37
https://doi.org/10.1016/S1381-5148(00)00033-X

[2] Deb S. Polymers in dentistry. J Eng Med 1998; 212: 453-464.
https://doi.org/10.1243/0954411981534213

[3] Hassan M, Asghar M, Din SU, Zafar MS. In Thermoset Polymethacrylate-Based Materials for Dental Applications. Elsevier: Amsterdam, The Netherlands 2019; 8: 273-308.
https://doi.org/10.1016/B978-0-12-816874-5.00008-6

[4] Nejatian T, Pezeshki S. Yaqin Syed AU. Acrylic denture base materials. In 5 Advanced Dental Biomaterials. Cambridge 2019; 79–104.
https://doi.org/10.1016/B978-0-08-102476-8.00005-0

[5] Zafar, MS. Prosthodontic Applications of Polymethyl Methacrylate (PMMA): An Update. Polymers 2020; 12(10): 2299.
https://doi.org/10.3390/polym12102299

[6] Bellini MP, Manchester KL. The Use of Poly(2-acrylamido-2-methyl-1-propanesulfonic Acid) Polymers as Spacers for Isotachophoresis in Sieving Gel Matrices. Analyt Biochem 1999; 268: 21-29.
https://doi.org/10.1006/abio.1998.2979

[7] Ladilova N, Kulikova G, Kornienko P, Shirshin KV, Shirshin KK. Impact of Conditions of Methyl Methacrylate Suspension Polymerization on the Particle Size Distribution of the Polymer. Rus J of App Chem 2023; 96: 429-433.
https://doi.org/10.1134/S1070427223040055

[8] Choul SH, Geun OH, Kangseok L, HLB, Soonja C. Emulsion polymerization of methyl methacrylate using the reverse iodine transfer polymerization (RITP) technique. Polymer 2009; 50: 4299-4307.
https://doi.org/10.1016/j.polymer.2009.06.074

[9] Villanova JCO, Ayres E, Carvalho SM, PatrÍcio PS, Pereira FV, Oréfice RL. Pharmaceutical acrylic beads obtained by suspension polymerization containing cellulose nano-whiskers as excipient for drug delivery. Eur J Pharmacol 2011; 42: 405-416.
https://doi.org/10.1016/j.ejps.2011.01.005

[10] Liyong Z, Guoxiang C, Cong F. Synthesis and characteristics of tyrosine imprinted beads via suspension polymerization. React Funct Polym 2003; 56: 167-173.
https://doi.org/10.1016/S1381-5148(03)00054-3

[11] Tan J, Zhao G, Lu Y, Zeng Z, Winnik MA. Synthesis of PMMA microparticles with a narrow size distribution by

photoinitiated RAFT dispersion polymerization with a macromonomer as the stabilizer. Macromolecules 2014; 47: 6856-6866. https://doi.org/10.1021/ma501432s

[12] Wang D, Yan R, Liu X, Su Y. Fabrication of hierarchical microparticles by depositing the in situ synthesized surface nanoparticles on microspheres during the seed emulsion polymerization. J Colloid Interf Sci 2012; 367: 249-256. https://doi.org/10.1016/j.jcis.2011.10.016

[13] Gao Y, Zhang J, Liang J, Yuan D, Zhao W. Research Progress of Poly(methyl methacrylate) Microspheres: Preparation, Functionalization and Application. Eur Polym J 2022; 175: 111379. https://doi.org/10.1016/j.eurpolymj.2022.111379

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https://doi.org/10.6000/1929-5995.2025.14.03