Experimental Study of the Strength Characteristics of a Modified Polymer Base Material for Use in Orthopedic Dentistry

O Shuliatnikova¹, G Rogozhnikov¹, S Porozova², A Rogozhnikov¹

¹ Dentistry Department of the E. A. Vagner Perm State Medical University, Russian Federation, Perm, 26 Kuibyshev Street
² Department of Mechanics of Composite Materials and Structures, Department of Aerospace, Perm National Research Polytechnic University

E-mail: anasko06@mail.ru

Abstract. Acquired defects of the maxillofacial region require orthopedic treatment. When choosing a structural material for the manufacture of a jaw prosthesis, it is necessary to provide for functional loads on the prosthesis during operation. Defects in the jaw bones require a structural material with high strength characteristics. The article deals with the method of increasing the strength of polyamide dental material with nanoscale titanium dioxide. Objective: to improve the strength characteristics of orthopedic structures made of polyamide. The study of the polyamide material was carried out on control and experimental samples, in which a modifying component was introduced by the method of dispersion reinforcement - nanoscale titanium dioxide in an amount of up to 1 wt.%. The three-point bending strength (σₘₐₓ, MPa) and Young's modulus (E, MPa) were experimentally studied. These parameters are indicative when assessing the strength of the basic structural materials from which removable dentures are made. These parameters take into account both vertical and horizontal functional loads, similar to the forces that arise when using removable dentures. The results of the study showed an increase in the maximum voltage by 8.4%, and the Young's modulus by 7.2% in samples with nanoscale titanium dioxide introduced into their composition to 1 wt. %. This study is of practical importance for orthopedic dentistry in cases where it is necessary to strengthen the structural base material in the manufacture of jaw prostheses for patients with acquired defects of the jaw bones, which reduces the risk of fracture of the base structures under the influence of functional loads.

Introduction

Acquired defects and deformities of the maxillofacial region require an orthopedic stage of treatment to fill in the aesthetic and functional parameters. In 95% of cases, removable structures of jaw prostheses are made of acrylic plastic [1], which has disadvantages: residual monomer, allergic reactions, shrinkage, disintegration of the structure during use, microbial contamination [2], [3]. At the present stage of development of dental materials science, basic structural materials are constantly being improved. This is due to the search for materials that have high strength and aesthetic characteristics. Known works on the development and implementation of polycarbonate, thermoplastics, carbodent, polystyrene, polyurethane. Of great interest for the manufacture of jaw prostheses are polyamide thermoplastics, which have minimal shrinkage during the manufacture of the prosthesis, a small specific weight, the absence of residual monomer and metal parts in the design of the prosthesis, the possibility of laboratory correction of the prostheses [4]. When choosing a structural material for the base of the prosthesis, it should be taken into account that the functional loads that the jaw prosthesis experiences will depend on the clinical situation and differ from the loads under normal conditions. This requires increased strength characteristics of the base polymer [5]. There are known options for improving the strength of the base material: reinforcement with metal meshes, reinforcement with aramid threads, etc.
Of particular interest are the nanocomponents introduced into the base material [6]. In minimal amounts, these components are able to change the physical and mechanical characteristics of the polymer [7]. The results of the study obtained earlier also indicate the ability of nanoscale titanium dioxide to inhibit biofilm formation [6]. This fact is of value in the manufacture of jaw prostheses [8], [9].

**The purpose** of this work was to study the strength characteristics of a polyamide material with nanoscale titanium dioxide introduced into its composition.

**Materials and methods of research**

The basis for the research of physical and mechanical properties was the international standard ISO 1567: 1999 Dentistry-Polymers based on dentures (Dentistry. Polymers for the bases of dentures).

Vertex ThermoSens (Vertex-Dental B. V., the Netherlands) was chosen as the construction material. This material is included in the 3rd class of basic materials according to the classification of the ISO-certificate 9001:2008 standard and is produced in the form of thermoplastic blanks or granules, its scope of application is the bases of removable partial and complete prostheses. Nanoscale titanium dioxide in the form of a powder (nanoparticle size 25-35 nm) was synthesized from an aqueous ethanol solution containing polymer additives. Dispersion-reinforced thermoplastics with nanoscale titanium dioxide introduced into the composition can increase the strength parameters of the structural material [10], [11]. In this regard, the study of the flexural strength ($\sigma_{\text{max}}$, MPa) and the elastic modulus (E, MPa) of the modified thermoplastics Vertex ThermoSens was of particular interest. The conducted method of research on three-point bending allowed us to evaluate the strength of the basic structural material, taking into account the vertical and horizontal loads, similar to those in the functioning of the dentofacial system and the structural materials of the bases of removable dentures during chewing load [12].

For the three-point bending tests, two groups of samples in the amount of 20 pieces with dimensions of 2×30×10 mm were made using the thermal injection molding technology and selected:

- Group 1 (control) basic material Vertex ThermoSens,
- Group 2 (experimental) basic material Vertex ThermoSens, with nanoscale titanium dioxide up to 1 wt % introduced into the composition.

Each group consisted of five samples. The experimental samples were measured with a geometric accuracy of 0.001 mm.

The research was carried out at the Center for Experimental Mechanics of the Department of Mechanics of Composite Materials and Structures of the Perm National Research University. The study of physical and mechanical parameters was carried out on the Instron 5965 electromechanical system with a maximum developed force of 5 Kn. The loading speed was 5 mm / min, at a temperature of +22 °C. Loading was carried out until the offset of 4 m was fixed, after which the test was stopped, and the sample was removed from the electromechanical system.

As a result of the tests, the force-deflection relationships were obtained. In the future, the transition to the stress-strain relationships was carried out.

We determined the Jung module, as in equation (1) and the maximum stresses, as in equation (2):

$$E = \frac{\Delta F l ^ 3}{4 b h ^ 2 \Delta w}$$  \hspace{1cm} (1)

$\Delta F$ - load gain, $\Delta w$ - the increase in deflection in the middle of the sample, in accordance with the change in load.

$$\sigma_{\text{max}} = \frac{3 F_{\text{max}} l}{2 b h ^ 2}$$  \hspace{1cm} (2)

$F_{\text{max}}$ - maximum load, $b$ - sample width, $h$ - sample height, $l$ - distance between supports.

For certain values for two groups of materials, statistical processing was performed with the allocation of a confidence interval with a probability of 95%.
Results and discussion

During the three-point bending tests, all 20 samples were not destroyed. The analysis of the obtained data after the test showed more favorable values of the maximum stresses and Young's modulus for the structural polyamide base material in the second experimental group of samples, where a modifying component—nanoscale titanium dioxide—was introduced into the composition by the method of dispersion reinforcement (Table 1).

| Group 1 (Vertex ThermoSens) | Group 2 (Vertex ThermoSens+TiO₂) |
|-----------------------------|----------------------------------|
| sample number | Flexural strength | Jung module | sample number | Flexural strength | Jung module |
|                | σ_{max}, MPa     | E, MPa       |                | σ_{max}, MPa     | E, MPa       |
| 1              | 96               | 1055         | 1              | 101              | 1089         |
| 2              | 92               | 986          | 2              | 105              | 1122         |
| 3              | 95               | 1058         | 3              | 103              | 1092         |
| 4              | 94               | 1028         | 4              | 102              | 1114         |
| 5              | 95               | 1050         | 5              | 105              | 1131         |
x_{ср±Δx} | 95±2 | 103±37 | x_{ср±Δx} | 103±2 | 1110±23 |

According to the results of tests of the physical and mechanical characteristics of experimental samples made of Vertex thermoplastics of both groups, we can say that they comply with the ISO 1567:1999 standard Dentistry-Polymers based on dentures (Dentistry. Polymers for the bases of dentures) and the current requirements for the basic construction materials for the manufacture of removable dentures. At the same time, the experimental samples made of Vertex ThermoSens polyamide with nanoscale titanium dioxide in the form of powder up to 1 wt.% introduced into the composition as a reinforcing component showed an increase in the maximum voltage by 8.4%, and the Young's modulus by 7.2% in comparison with the experimental samples of the first group, which do not contain nanoscale titanium dioxide.

Conclusion

According to the results of the tests carried out, we can state the following conclusions:

1. Modification by dispersion reinforcement of the polyamide material Vertex ThermoSens with nanoscale titanium dioxide in the form of a powder in an amount of up to 1 wt. % increases the maximum voltage by 8.4% and the Young's modulus by 7.2%.
2. The conducted studies on the three-point bending of experimental samples of the polyamide structural base material Vertex ThermoSens, reinforced with nanoscale titanium dioxide, showed their compliance with the international standard ISO 1567:1999 Dentistry-Polymers based on dentures (Dentistry. Polymers for denture bases).

Thus, the results of experimental studies and previously published materials on the possibility of inhibiting the formation of biofilm on a structural material with a surface nanomodified layer of titanium dioxide have a promising direction in the field of practical orthopedic dentistry, namely, in the manufacture of removable jaw prostheses and removable devices for patients with fractures, acquired defects and deformities of the maxillofacial region and patients with dental defects of various lengths. Such improved properties of the structural base material contribute to reducing the risk of possible inflammatory complications in patients of these categories. In addition, the modified polyamide base material is able to easily withstand the functional loads that occur during the operation of removable dentures, preventing breakdowns of the prosthesis structures.

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