Сучасні підходи до проектування інформаційних систем надають гнучкі та масштабовані рішення, які можуть адаптуватися до змінних вимог бізнесу та технологій. Вибір конкретного підходу або їх комбінація залежить від специфіки проекту та вимог замовника.

Література:

1. Томашевський О. М., Цегелик М. Б., Вітер Г. Г., Дубук В. І. Інформаційні технології та моделювання бізнеспроцесів : навчальний посібник. К. : Центр учбової літератури, 2005. 296 с.
2. Білоскурський Р. Р. Концептуальні основи гнучкого управління проєктами розроблення та впровадження інформаційних систем. *Науковий вісник Ужгородського національного університету. Серія : Міжнародні відносинита світове господарство.* 2022. Вип. 41. С. 10–13.

DOI https://doi.org/10.30525/978-9934-26-446-7-53

DEVELOPMENT OF BIOCOMPATIBLE TITANIUM ALLOYS FOR IMPLANTS

РОЗВИТОК БІОСУМІСНИХ ТИТАНОВИХ СПЛАВІВ ДЛЯ ІМПЛАНТАТІВ

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As it is well-known, implants are used for the purpose of full or partial replacement of lost or diseased organs to restore their form and function and are made of natural or artificial biomaterials. In particular, diseases such as osteoporosis (weakening of bones), osteoarthritis (inflammation of bone joints) and injuries are the reason for bone replacement. As the majority of the population over 40 years of age suffers from degenerative diseases and the number of elderly people is increasing, biomaterials help to improve the quality of life and longevity of people and show rapid growth to meet the needs of the aging population.

According to the impact of implants on the body, the following are distinguished: toxic materials causing negative immune and pathological changes; bioinert – non-toxic materials, resistant to biochemical effects of the body and limited to a layer of fibrous tissue; and bioactive, which integrate with bone tissue, are gradually resorbed and replaced without toxicity [1, p. 815]. In order for the implant to perform the specified functions, the material from which it is made must have certain properties: biological, physicochemical, and mechanical.

Materials used for orthopedic implants, especially for load-bearing applications, must meet the requirements for biocompatibility: high strength and a low elastic modulus, high fatigue, wear and corrosion resistance [2, p. 400]. Regarding the biomechanical compatibility of many metallic materials, Ti-based alloys appear to have an overall advantage, even though they are more expensive.

Until now, the most common material for manufacturing implants is technically pure titanium VT1-0. In particular, pure titanium has a fairly high corrosion resistance and is resistant to salt solutions, which are considered aggressive environments. Therefore, titanium is biologically inert and one of the most suitable materials for bone surgery, orthopedics, and dentistry, but the strength of pure titanium does not allow its use for the manufacture of implants capable of withstanding significant loads [2, p. 403].

The combination of low reactivity and high strength makes titanium-based alloys one of the best materials for use in bone surgery [2, p. 403, 412]. For a long period, the main biomedical titanium alloy was Ti–6Al–4V (VT6) developed for structural materials, but it has some disadvantages, and its use as a biomaterial is gradually declining. When the alloy is implanted into the body's physiological environment, metal ions are released over time, so it must have a non-toxic chemical composition. Alloying additives VT6 (V, Al) improve the mechanical properties of titanium but significantly worsen the biological ones due to a certain cytotoxic effect of vanadium and the negative impact of aluminum on the human body. In addition, the elasticity modulus of Ti–6Al–4V [2, p. 402] is incompatible with bone tissue that can lead to stress, bone resorption, and premature failure of the implant. New types of alloys that do not contain toxic V, such as Ti–6Al–7Nb and Ti–5Al–2.5Fe, have been created [2, p. 403, 411]. These alloys are wear-resistant, used mainly in dentistry, or in joint prostheses, and are usually produced by casting.

Titanium alloys for biomedical use without V and Al, which are harmful to the human body, containing non-toxic bioinert elements Nb, Ta, Zr, etc., have also been developed [3, p. 5706]. These are mainly β-alloys with a high content of β-stabilizers, which lower the modulus of elasticity, thus bringing it closer to the modulus of elasticity of bone. β-Titanium alloys also have many advantages in mechanical properties, such as improved wear resistance, high ductility, and excellent cold and hot formability.

Modern research is aimed at creating materials with greater biocompatibility for a new generation of implants – alloys based on the Ti-Nb system [4, p. 125] which are doped with β-eutectoid silicon stabilizer [5, p. 887], [6, p. 815]. Biocompatibility of pure niobium *in vitro* was shown when it was used as a coating on a stainless steel implant [7, p. 72]. Silicon has a positive effect on regenerative processes in bone tissue [8, p. 902] and enhances the osteointegration properties of implants.

In Ti-Nb-Si alloys, due to the combined action of niobium and silicon alloying elements, both solid-solution and dispersion strengthening is realized as a result of the release of silicides [9, p. 363]. For greater strengthening and reduction of the elastic modulus, these alloys are additionally alloyed with biocompatible zirconium [10, p. 237]. Such alloys can be used for osteointegration prosthetics, which has become very relevant for high amputations of limbs in the conditions of military operations and has been actively developing recently.

Considering the high cost of niobium, research is also being conducted into the possibility of reducing its content in biocompatible alloys of the Ti-Nb-Si system [11, p. 1061]. Alloys with the structure of metastable β and α″ phases have a reduced modulus of elasticity, with its minimum values in the areas of critical concentrations of the alloying element – α′/α″ and α″/β transitions [12, p. 2777]. Thus, new biomedical titanium alloys with Nb content ≤ 18 wt. % have recently been proposed and are currently under development.

A lot of attention is now also paid to another area of development of materials for implants – the study of biomedical alloys doped with antibacterial components [13, p. 2569], especially Cu [14, p. 5212]. Implant-related infection or inflammation is fairly common cause of failed implantation, while antibiotic therapy is not always helpful. However, further prospects for the development of titanium alloys for implantation lie not only in the creation of new alloys, but also in the development of technologies for their production, traditional and additive, related to powder metallurgy and 3D printing [15, p. 1709].

References:

1. Anselme K., Noël B., and Hardouin P. Human Osteoblast Adhesion on Titanium Alloy, Stainless Steel, Glass and Plastic Substrates with Same Surface Topography. *J. Mater. Sci.: Mater. Med*. 1999. Vol. 10(12). P. 815–819.

2. Geetha M., Singh A. K., Asokamani R., and Gogia A. K. Ti Based Biomaterials, the Ultimate Choice for Orthopaedic Implants – A review. *Progress in Materials Science*. 2009. Vol. 54. P. 397–425.

3. Eisenbarth E., Velten D., Müller M., Thull R., and Breme J. Biocompatibility of β-stabilizing Elements of Titanium Alloys. *Biomaterials*. 2004. Vol. 25(26). P. 5705–5713.

4. Zhang Y., Sun D., Cheng J., Tsoi J. K. H., and Chen J. Mechanical and Biological Properties of Ti–(0–25 wt%)Nb Alloys for Biomedical Implants Application. *Regen. Biomater.* 2020. Vol. 7(1). P. 119–127.

5. Kim H. S., Kim W. Y., and Lim S. H. Microstructure and Elastic Modulus of Ti-Nb-Si Ternary Alloys for Biomedical Applications. *Scripta Mater*. 2006. Vol. 54(5). P. 887–891.

6. Shevchenko O. M., Kulak L. D., Kuzmenko M. M., Kotko A. V., and Firstov S. O. Investigation of Structure of the Quenched Cast Biocompatible Ti–18Nb–*x*Si Alloys. *Metallofiz. Noveishie Tekhnol.* 2017. Vol. 39(6). P. 815–829.

7. Olivares–Navarrete R., Olaya J. J., Ramírez C., and Rodil S. E. Biocompatibility of Niobium Coatings. *Coatings*. 2011. Vol. 1. P. 72–87.

8. Shevchenko O. M., Kulak L. D., Kuzmenko M. M., Koval O. Yu., Kotko A. V., Ulyanchich N. V., Piven O. O., Ruban T. P., and Firstov S. O. Investigation of Influence of Heat Treatment on Structure and Properties of Biocompatible Ti–18Nb–xSi Alloys. *Metallophiz. Noveyshye Tekhnol*. 2021. Vol. 43(7). P. 887–907.

9. Shevchenko O. M., Kulak L. D., Kuzmenko M. M., and Firstov S. O. Structure Formation of as Cast Biocompatible Alloys of the Ti-Nb-Si System. *Metallofiz. Noveishie Tekhnol*. 2019. Vol. 41(3). P. 363–374.

10. Shevchenko O. M., Kulak L. D., Kuzmenko M. M., and Firstov S. O. Influence of Zirconium Alloying at the Structure and Hardness of the Quenched Cast Biocompatible Alloy Ti-18Nb-1Si. *Metallofiz. Noveishie Tekhnol.* 2020. Vol. 42(2). P. 237–249.

11. Shevchenko O. M., Kulak L. D., Kuzmenko M. M., Koval O. Yu., and Firstov S. O. Influence of Niobium and Silicon at the Structure of Biocompatible Ti-xNb-(1÷1,2)Si Alloys, as Cast and after Heat Treatment. *Metallofiz. Noveishie Tekhnol*. 2022. Vol. 44(8). P. 1059–1075.

12. Ozaki T., Matsumoto H., Watanabe S., and Hanada S. Beta Ti Alloys with Low Young's Modulus. *Mater. Trans.* 2004. Vol. 45 (8). P. 2776–2779.

13. Zhang E., Zhao X., Hu J., Wang R., Fu Sh., and Qin G. Antibacterial Metals and Alloys for Potential Biomedical Implants. *Bioactive Materials*. 2021. Vol. 6. P. 2569 – 2612.

14. Zhao Zh., Xu W., Xin H., and Yu F. Microstructure, Corrosion and Anti-bacterial Investigation of Novel Ti-xNb-yCu Alloy for Biomedical Implant Application. *J. Mater. Research and Technology*. 2022. Vol. 18. P. 5212–5225.

15. Li Y., Yang Ch., Zhao H., Qu Sh., Li X., and Li Y. New Developments of Ti-Based Alloys for Biomedical Applications. *Materials.* 2014. Vol. 7. P. 1709–1800.