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MATERIALS FOR TOTAL HIP JOINT PROSTHESES: BIAXIAL FLEXURAL STRENGTH OF TWO CERAMIC SYSTEMS

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ABSTRACT

Total hip joint replacement is one of the most successful orthopaedic surgeries in the last decade. Essential part of total hip joint prostheses is the mobile joint "hemispherical head - hemispherical cup". Functional properties and durability of the implanted prosthesis in the human body depend crucially on the mechanical and tribological properties and characteristics of materials of articulated parts.

Development and improvement of implant technology are inextricably linked with the development of new materials and, in particular, new ceramic materials with improved mechanical characteristics. This in turn requires improving methods of preliminary testing and evaluation of these characteristics.

In the paper materials for hip prostheses and methods for evaluation of their mechanical characteristics are briefly reviewed. The results of preliminary studies on some characteristics of reinforced titanium ceramics are presented.

KEYWORDS: bioceramics, flexural strength

1. Introduction

Along with high biocompatibility and durability of materials used for hip replacement are their mechanical properties.

There are a number of standardized procedures for determination of suitability of different materials.

For making different types of prostheses are used as metal (steel and titanium) alloys and various types of ceramics.

Two types of ceramic materials are used in practice - type A and type B. Type A ceramic materials for implants are subjected to high loads (bearing surfaces of joint implants), and type B materials are intended for use in implants with small loads (implants for middle ear).

Fundamental mechanical tests for ceramic materials for arthroplasty under ISO 6474:1994 (E) relating to the definition of average biaxial flexure load and wear resistance of the material, such as durability of the material are examined in cases where there is articulation of ceramics on ceramics.

2. Biaxial flexure testing

When examining the biaxial flexure load [1], a disk made of research material is placed between two coaxial rings of different diameters.

Gradually increasing compressive load is applied and its value at fracture of the specimen is registered. The Flexural Strength is calculated based on the results of the recorded fracture load (F).

The specimen, loading and supporting are shown schematically in Fig. 1 and Fig. 2a, Fig. 2b.

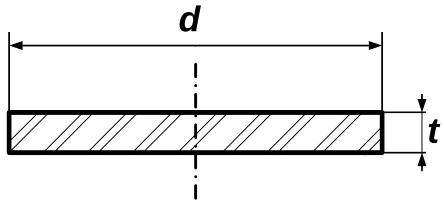
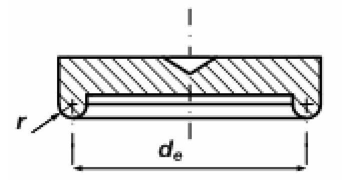


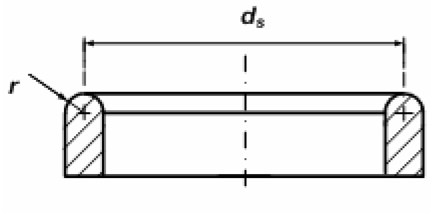
Fig.1. *Shape and dimensions of the specimen*

Principle scheme of measuring the strength of biaxial flexure is presented in Fig.3.

Between the supporting ring (2) and the specimen (3), a rubber pad (8) is placed to exclude the influence of shape deviations of the contact surfaces of the specimen and the rings. The loading ring (4) transmits the load to the specimen through a thin paper pad (7). For A uniform distribution of the load on the specimen, the load given by the loading device of the machine for testing tension/compression load (6) is transmitted through the metal sphere (5) to the loading ring (4)



a)



b)

Fig.2. *Loading (a) and supporting (b) rings.*

The fracture load F of the specimen is registered. The flexural strength is given by:

$$\sigma = \frac{3F}{2\pi t^2}\left[(1+\nu)\ln\left(\frac{d_s}{d_e}\right) + (1-\nu)\left(\frac{d_s^2 - d_e^2}{2d^2}\right)\right] \quad (1)$$

Where:

t – mean thickness, determined by 3 measurements of the specimen, mm;

d_s – average contact diameter of the supporting ring, mm;

d_e - average contact diameter of the loading ring, mm;

d - average diameter of the specimen, mm;

ν – Poisson's ratio was taken as 0.25 for all ceramics according to the recommendation in the standard.

The specimens are loaded in a universal testing machine INZTRON 1195. The loads applied to the surface of the specimen via loading ring at a rate of 540N/s.

The diameters of the contact circles of the supporting and loading rings are d_e = 12.01, mm and ds=30,14, mm, radius of the curvature of the contact surface with the specimen is r = 2.01 mm. Rubber pad placed between the specimen and the supporting ring has a 0.6mm thickness and scleroscope hardness 62. The contact surfaces of the rings are hardened to 42 HRC.

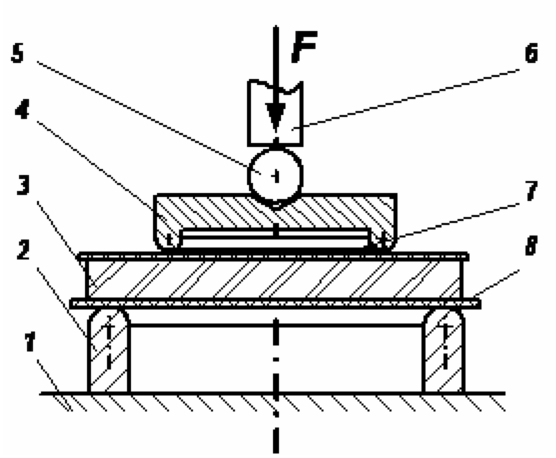


Fig.3. *Loading Scheme*
1–base; 2–supporting ring; 3–specimen; 4–loading ring; 5–contact sphere; 6-loading element; 7–paper pad; 8–rubber plate.

The diameters of the contact circles of the supporting and loading rings are d_e = 12.01 mm and d_s = 30.14 mm, radius of the curvature of the contact surface with the specimen is r = 2.01 mm. Rubber pad placed between the specimen and the supporting ring has a 0.6 mm thickness and scleroscope hardness 62. The contact surfaces of the rings are hardened to 42 HRC.

3. Materials and results

Materials used in the paper are aluminium and reinforced titanium ceramics. The test specimens [3] are obtained by the same technology used for making hip-joints femoral heads.

Aluminium ceramic

Ten pieces of "MARTOXID" ceramic (99.5% Al_2O_3 and 0.3% MgO) [2] MartinSWERK, used for manufacturing hip-joint prosthesis, were subjected to flexural strength test.

The dimensions of the specimens – diameter (d_m) and thickness (t_m), are given in Table 1. In the same table are given values of the fracture load F and defined according to formula flexural strength.

Reinforced titanium ceramic

The ceramic specimens tested were prepared by mixing TiO_2 and Nb_2O_5 powders in proportions ensuring concentration of 8wt.%. Nb_2O_5 in the final product. The preparation of the samples is described in details in [Teodosiev and all Artcast Galati] [4].

The prepared specimens were sintered at temperature of 1450ºC (8 specimens) and 1520º (8 specimens) according to a predetermined temperature regime. The dimensions of the specimens - diameter (d_m) and thickness (t_m), are given in Tables 2 and 3 for type 1 and 2. In the same tables are given values of the fracture load (F) and flexural strength.

The tested specimens after fracture are shown in Fig. 4, 5 and 6.

Table.1. *Specimens dimensions and test results for "MARTOXID" ceramic*

Specimen №	Diameter	Thickness	Load at rapture		Biaxial flexure strength at rapture
	d_m, mm	t_m, mm	Load F, kg	Load F, N	σ, MPa
1	36.00	2.28	215	2109.2	265.6431
2	35.83	2.126	185	1814.9	263.2938
3	36.13	2.168	200	1962.0	272.9844
4	36.23	2.144	195	1913.0	271.9115
5	36.30	2.086	180	1765.8	264.9839
6	36.27	2.17	195	1913.0	265.3413
7	35.77	2.128	185	1814.9	262.9425
8	35.97	2.152	195	1913.0	270.5183
9	36.27	2.168	190	1863.9	259.0150
10	36.03	2.13	180	1765.8	254.7572
			$\bar{\sigma}$, MPa		**265.1391**
			s, MPa		**5.678312**

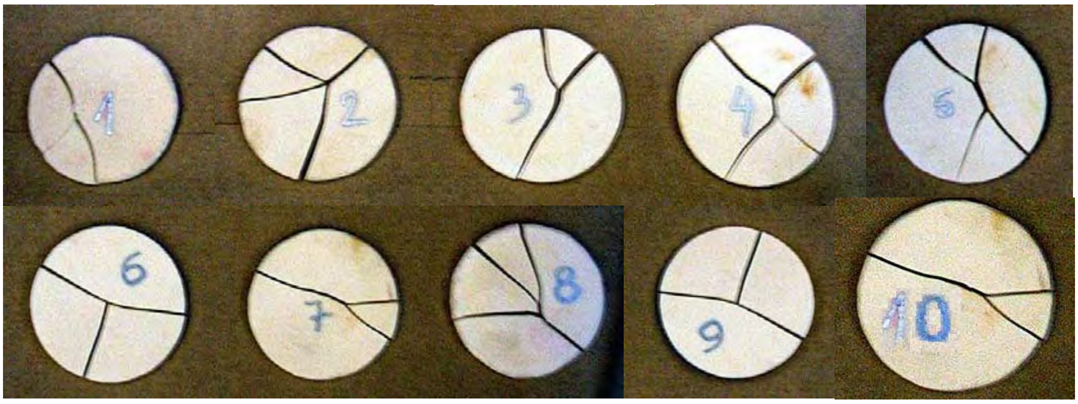


Fig.4. *Specimens from "MARTOXID" ceramic after fracture*

Table.2 *Specimens dimensions and test results for reinforce titanium ceramic – type 1*

Specimen №	Diameter	Thickness	Load at rapture	Biaxial flexure strength at rapture
	d_m, mm	t_m, mm	Load F, N	σ, MPa
1 -1	34.25	1.976	533	90.90
1 -2	34.08	2.042	494	79.00
1 -3	34.24	1.950	486	85.10
1 -4	34.15	2.160	750	107.2
1 -5	34.30	2.080	673	103.5
1 -6	34.13	2.120	984	145.9
1 -7	34.30	2.120	751	111.2
1 -8	34.20	2.124	733	108.2
			$\bar{\sigma}$, MPa	103.87
			s, MPa	19.33

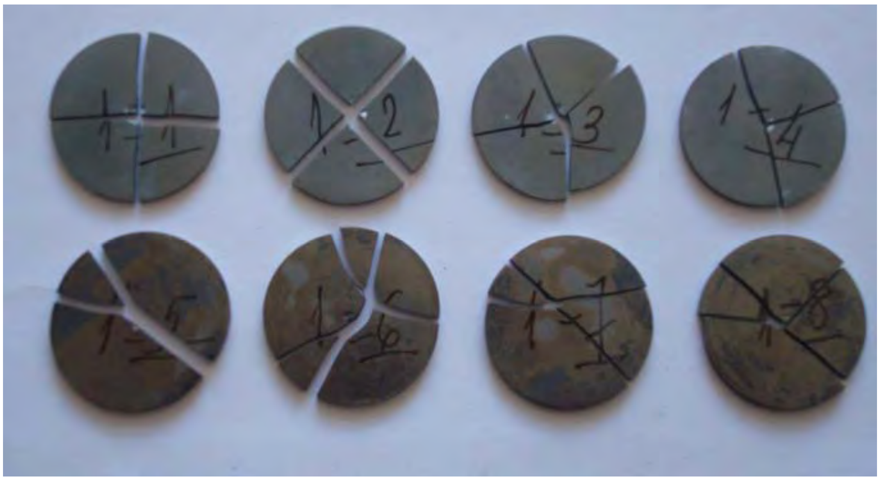


Fig.5. *Specimens from reinforced titanium ceramic – type 1 after fracture.*

Table.3 *Specimens dimensions and test results for reinforce titanium ceramic – type 2*

Specimen №	**Diameter**	**Thickness**	**Load at rapture**	**Biaxial flexure strength at rapture**
	d_m, mm	t_m, mm	**Load** F, N	**σ,** MPa
2-1	34.32	2.244	538	71.1
2-2	34.8	2.215	919	124.0
2-3	34.25	1.980	458	77.8
2-4	34.3	2.080	720	110.7
2-5	34.23	2.183	901	126.0
2-6	34.16	2.081	640	98.5
2-7	34.16	2.124	556	82.1
2-8	34.45	2.213	720	97.7
			$\bar{\sigma}$, MPa	98.48
			s, MPa	19.37

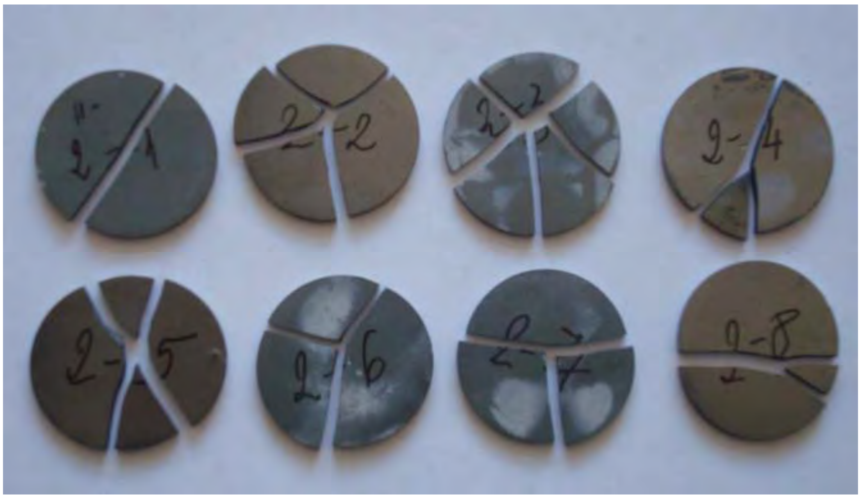


Fig.6. *Specimens from reinforced titanium ceramic – type 2 after fracture.*

Conclusions

Studied samples of ceramics "MARTOXID", MartinSWERK, showed that the average flexural strength at biaxial flexure testing is σ;¯ =265.1 MPa. According to the requirements of the standard the minimum flexural strength is σ;¯ min= 50MPa.

Therefore the tested samples meet the requirements of the regulations for type A and ceramics can be used in a production to implants subjected to large loads.

The average flexural strength of titanium ceramic samples does not meet the requirements. For further investigation of these ceramics, their manufacturing technology must be improved so they can meet the requirements for hip-joint prosthesis.

Acknowledgements

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