

## CORRELATION BETWEEN STRUCTURE AND PROPERTIES OF A TOOL STEEL USED IN SURGICAL INSTRUMENTS

Daniela Alina NECȘULESCU<sup>1\*</sup>, Aurora ANTONIAC<sup>2</sup>, Răzvan Ionuț POPESCU<sup>3</sup>, Mariana CIURDAȘ<sup>4</sup>, Alexandru STREZA<sup>5</sup>, Anca Maria FRĂȚILĂ<sup>6</sup>

*Medical instruments represent the set of devices, equipment and tools used by medical professionals to ensure effective and safe patient care. It includes both surgical instruments and diagnostic equipment. All these instruments are designed with precision and subject to strict quality controls, to meet the high standards of medical practice. The most used materials for the manufacture of medical instruments are titanium, stainless steel and high-alloy tool steel coated with chromium, as they have most of the properties of the materials used in the human body: chemical, thermal and mechanical stability, biocompatibility. In this paper, the aim was to determine the chemical composition and structural characterization of a reference instrument used in medical practice.*

**Keywords:** Medical instruments, spectroscopy, optical microscopy, hardness

### 1. Introduction

Medical instruments represent the set of devices, equipment and tools used by medical professionals to ensure efficient and safe patient care. It includes both surgical instruments – such as scalpels, forceps, retractors – and diagnostic equipment, such as imaging equipment, tensiometers or laboratory devices. All these instruments are designed with precision and subject to strict quality controls, to meet the high standards of medical practice. Personnel involved in surgical interventions must have solid knowledge of the use and operation of each instrument, to ensure the optimal performance of the surgical act. The most

---

<sup>1</sup> Lecturer, Faculty of Material Science and Engineering, The National University of Science and Technology POLITEHNICA Bucharest, Romania, e-mail: alina.necsulescu@upb.ro

<sup>2</sup> Researcher, Faculty of Material Science and Engineering, The National University of Science and Technology POLITEHNICA Bucharest, Romania, e-mail: antoniac.aurora@gmail.com

<sup>3</sup> Asist., Faculty of Medicine - Department 3 - Nephrology, Urology, Immunology and Transplant Immunology, Dermatology, Allergology, Romania, e-mail: dr.razvanp@gmail.com

<sup>4</sup> Lecturer, Faculty of Material Science and Engineering, The National University of Science and Technology POLITEHNICA Bucharest, Romania, e-mail: mariana.ciurdas@upb.ro

<sup>5</sup> Eng., Faculty of Material Science and Engineering, The National University of Science and Technology POLITEHNICA Bucharest, Romania, e-mail: alexandru.streza@upb.ro

<sup>6</sup> Lecturer, Faculty of Medicine, Lucian Blaga University of Sibiu, Romania, e-mail: anca.fratila@ulbsibiu.ro

frequently used materials for the manufacture of medical instruments are titanium and stainless steel, as they have most of the properties of the materials used in the human body: chemical, thermal and mechanical stability, biocompatibility [1].

Different methods were used by different research group for analyzing the correlations between functional properties of each type of surgical instrument and events that could appear during clinical use of surgical instruments [2-8].

Stainless steel is one of the most widely used materials in the medical field, especially for the manufacture of surgical instruments and various medical devices. This choice is based on a remarkable set of properties that meet the strict requirements imposed by use in the biological environment [9].

Common types of stainless steel used in surgical instruments are austenitic and martensitic. Austenitic stainless steels like 316L offers excellent corrosion resistance, is highly biocompatible, and is easy to process into various shapes. It is commonly used in non-cutting tools, forceps, and needle holder bodies.

One of the most important characteristics of stainless steel is its high resistance to corrosion [10], essential in the context of repeated exposure to body fluids, saline solutions, antiseptic agents and aggressive sterilization processes, such as autoclaving or exposure to steam under pressure. This resistance is due to the high chromium content (over 10.5%), which forms a passive oxide layer that protects the metal surface from the corrosive action of the environment.

Martensitic stainless steels like 420 or 440C are used for instruments requiring sharpness and wear resistance. Typical applications include blades, bone drills, osteotomes, and chisels. Microstructural aspects of metallic materials influence strongly their mechanical and corrosion properties, that are important for surgical instruments [11-14]

Surface properties are essential not just for implants but also for surgical instruments because could produce infections [15-17]

One of the most widely used instruments is the medical chisel, which is used to cut, shape, or remove hard tissues or structures, mainly bone, during surgical procedures. Chisels are usually used in conjunction with a surgical hammer to apply controlled force to the blade, thus allowing for precise and efficient cutting [18].

The medical chisel has the following characteristics:

- Sharp blade: The blade is made of stainless steel or other resistant materials, to ensure durability and ease in cutting hard tissues.
- Variable shape and size: Chisels can have straight or curved blades, and their size and angle can vary depending on the type of surgery.
- Ergonomic handle: The handle is designed to provide a firm grip and precise control, and the material from which it is made is usually durable and resistant to sterilization.

Medical chisels are used in several medical fields, such as (Fig. 1):

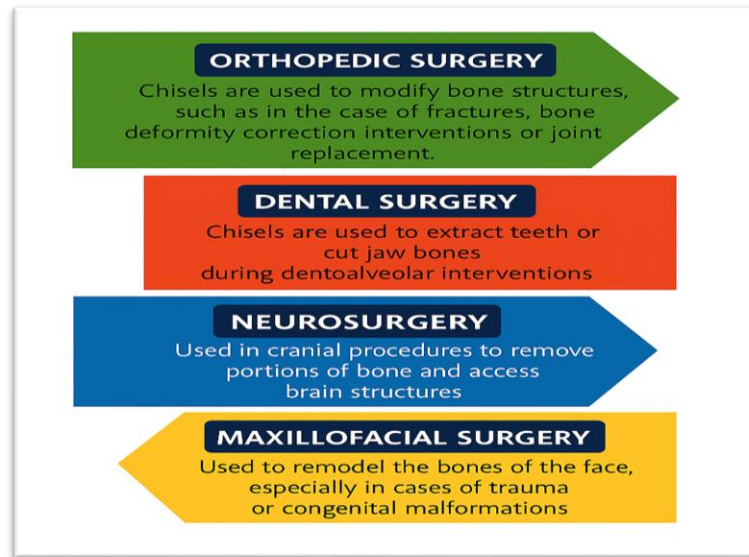


Fig.1. Uses of medical chisels

High-alloy tool steels are specialized ferritic alloys [19], characterized by a high content of alloying elements (generally >5%), used for the manufacture of cutting tools, plastic deformation or hot working tools, which must withstand extreme thermomechanical stress, wear and shock (Fig. 2).

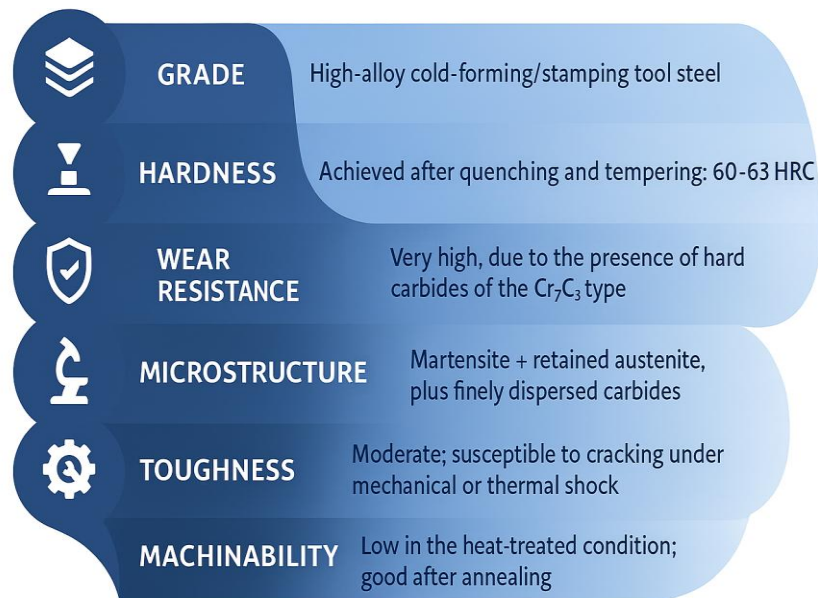


Fig. 2. Essential characteristics of tool steel

The most relevant values/characteristics of tool steel properties [20] are presented in table 1:

Table 1

Main values/characteristics	
Property	Value / Characteristic
Hardness	58 – 62 HRC, depending on heat treatment
Heat resistance	Retains hardness at 500–600°C (HSS even higher)
Toughness	Average to good, but dependent on composition and treatment
Wear resistance	Very high due to finely dispersed hard carbides
Machinability	Low, but acceptable before final treatments

## 2. Materials and methods

### 2.1. Determination of chemical composition by optical emission spectrometry by arc and electric spark SDAR-OES

Experimental research was conducted on a medical instrument, namely a chisel, represented in Fig. 3.

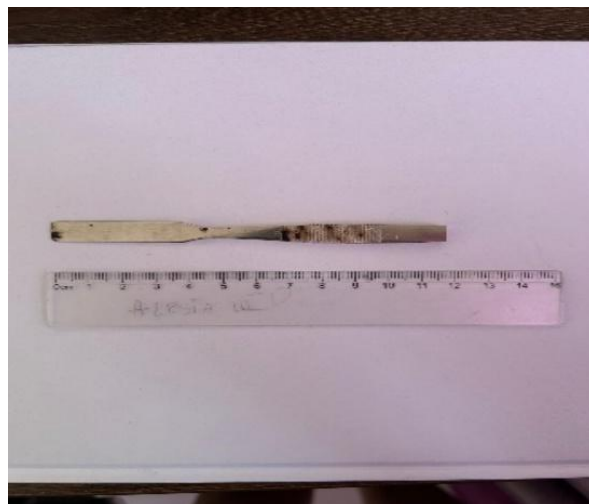


Fig 3. The chisel used for testing

To determine the chemical composition, the SPECTROMAX equipment was used, which has analytical programs designed for the analysis of low and medium alloy steels, tool steels, stainless steels, steels for automatic processing, manganese steels, resistive steels, cast irons, Cu-based alloys, Ni-based alloys, Co-based alloys, Stellite-type alloys, Pb-based alloys, Sn-based alloys, Mg-based alloys, Ti-based alloys, Zn-Al-type alloys and Zn-Al-Pb-type alloys.

### ***2.2. Optical microscopy***

Metallographic analysis was performed using a NIKON ECLIPSE MA100N microscope.

Optical microscopy is a fundamental technique for observing samples using visible light and optical lenses. It is one of the oldest and most widely used methods of microscopic investigation, with wide applications in biology, medicine, chemistry, and materials science.

### ***2.3. Hardness measurements***

For the chosen sample, hardness was determined by the Vickers method. This process involves carrying out experimental determinations in several areas of the sample to highlight the hardness, followed by the comparison of the obtained results. The Vickers method uses a diamond pyramid with a square-shaped base as the penetrator. Due to its clearly superior hardness compared to other industrial materials, diamond allows the application of the method without restrictions in the determination of hardness. This procedure is recommended for evaluating the hardness of materials with a probable hardness greater than 300 daN/mm<sup>2</sup>. For the experimental hardness test was used a Micro-Vickers CV-400 DTS hardness tester.

## **3. Results and discussions**

Samples of square size 20 mm x 20 mm were used to determine the chemical composition by fluorescence spectroscopy using a SPECTROMAX type apparatus.

### ***3.1. Determination of chemical composition. Arc and spark optical emission spectrometric analysis***

Following the spectrometric analysis of optical emission through arc and spark, we obtained the following results (table 2):

Table 2

Chemical composition of the chisel

C	Mn	Cr	Mo	Si	P	S	Fe
1.80%	0.70%	11.60%	0.02%	0.40%	0.04%	0.03%	85.41%

The steel falls into the category of a high-alloy tool steel, the class of ledeburite steels, and can be assimilated to 200Cr120 steel.

### 3.2. Metallographic analysis by optical microscopy

Both cross and longitudinal section samples were analysed. For optical microscopy studies, the samples followed the standard metallographic preparation procedure, by grinding, polishing and metallographic etching with 2% NITAL reagent. (Fig. 4).



Fig. 4. Prepared metallographic sample

Structural investigations were performed both at low magnifications ( $M=100\times$ ) to obtain an overall picture of the structure, but also at higher magnifications to detail certain areas of the structure that are of interest.

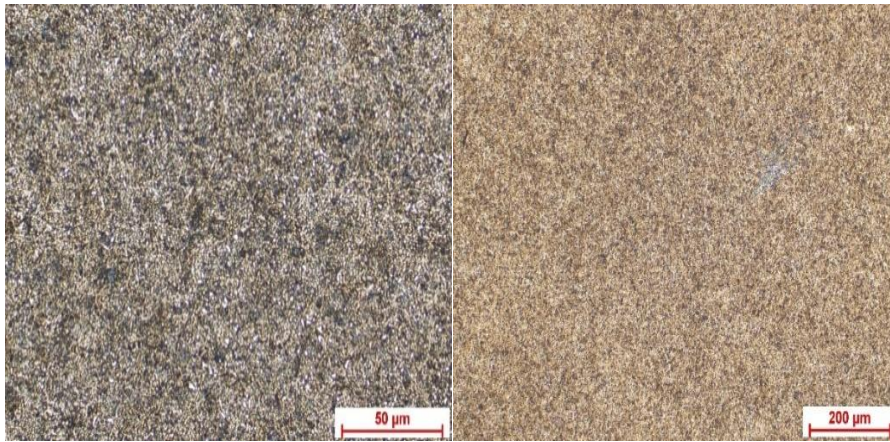


Fig. 5. Optical microscopy images(a,b)

At low magnifications  $M=100\times$ , Fig. 5 a, a fine structure formed by tempering martensite (dark, slightly acicular areas) and finely dispersed carbides is observed. Higher magnifications  $M=500\times$ , Fig. 5 b, allow a more detailed identification of the carbides. These are either with fine globular edges (secondary carbides) or with slightly polyhedral shapes in which primary carbides are recognized. At the same time, certain light, fine networks are also noticed, which belong to a small amount of residual austenite.

These structural details lead to the conclusion that the steel was subjected to a martensitic hardening and low tempering heat treatment, a secondary heat treatment specific to 200Cr120 steel. The average hardness values ( $\mu\text{HV}=590\div 610$ ) are correctly associated with the structure, also attesting from the point of view of mechanical properties the heat treatment applied.

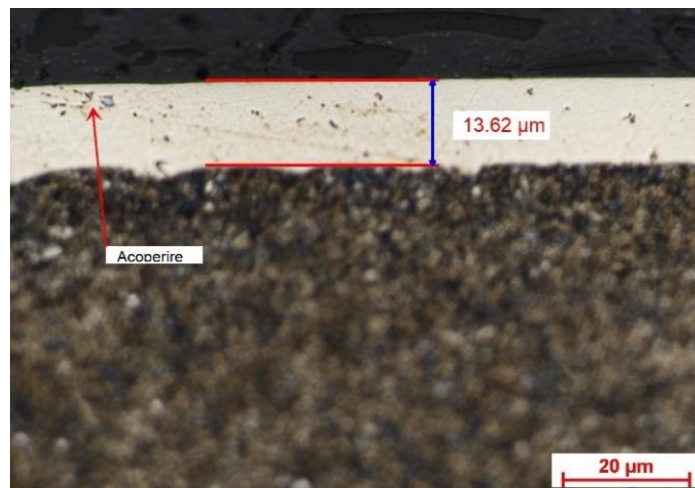


Fig. 6. Optical microscopy image in cross-section  $M=1000\times$  (2% Nital attack)

The microscopic analysis in cross-section (Fig. 6) brings as a novelty structural details related to the external area of the chisel. This highlights a bright layer of approximate thickness  $\delta = 13.62 \mu\text{m}$ , which corresponds to a galvanic coating with Cr, the medical instrument being finally subjected to a chrome plating to increase corrosion resistance. The deposited layer seems uniform, but the roughness of the chisel was not very small. The unevenness in the base metal material visible in the microstructure suggests a rather poor finishing. A detail that draws attention in the morphology of the coatings is the rather dense dispersion of brown or grey-blue particles. These are certainly exogenous particles, that most likely occur due to a contaminated galvanic bath. They negatively affect the quality of the deposition, i.e. the corrosion behaviour.

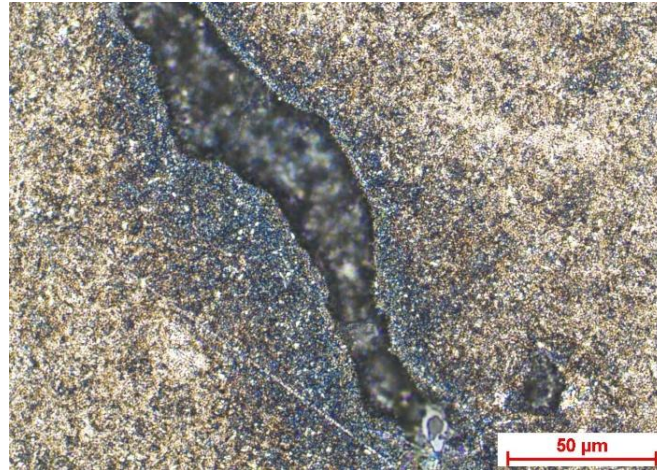


Fig. 7. Optical microscopy image in longitudinal section with corroded area M=1000x (Nital 2%)

Fig. 7 captures a corroded area from a microregion of the sample in longitudinal section. The image shows significant corrosion, distributed in a wavy, meandering direction of approximately 170-180  $\mu\text{m}$ , surrounded by oxidized edges.

In the corrosion area proper, the steel appears locally destroyed by dissolution, weakening both its mechanical strength properties and its chemical resistance behaviour, through the diffusion of metal ions in the surrounding chemically active environment. Both the decrease in mechanical properties and the alteration of corrosion behaviour are harmful factors, harmful to health, considering the functionality of the analysed medical instruments. The cause of this corrosion can be attributed to the exogenous inclusions reported in the composition of the chrome layer. These created local galvanic micropyles in the chemically active environment (the actual working environment, the action of sterilization liquids, etc.) which ultimately produced corrosion effects in the layer. These amplified over time, and the chrome layer no longer created protective action on the tool steel. The

result is the significant corrosion captured in the image in Fig. 39 and which can put the medical instrument out of operation.

### 3.3. Hardness measurements results

To measure the microhardness, a sample was taken from the chisel, preparing the surface of the piece to a roughness that would allow the determination and measurement of the traces under good conditions. The force with which the test was performed was established. The device used in the laboratory was CV Instruments.

-Technical parameters: Dwell time: 30 s, 500 gf

Table 2

**Hardness test results**

No. of tests	Diagonal 1	Diagonal 2	Hardness
Value 1	38	40	618 HV
Value 2	39	39	605 HV
Value 3	25	25	610 HV
Average	34	35	611 HV

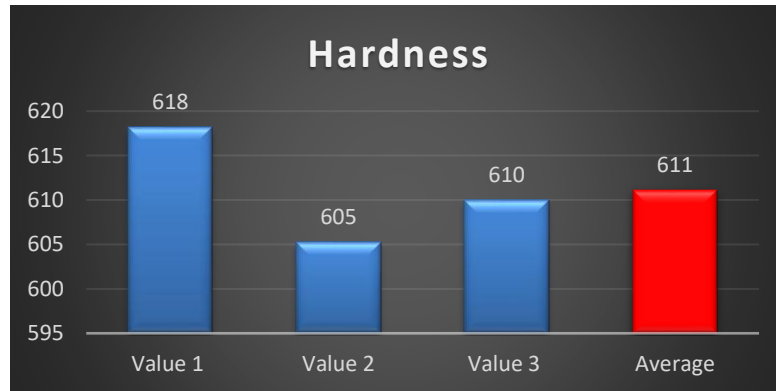


Fig 8. Hardness test results

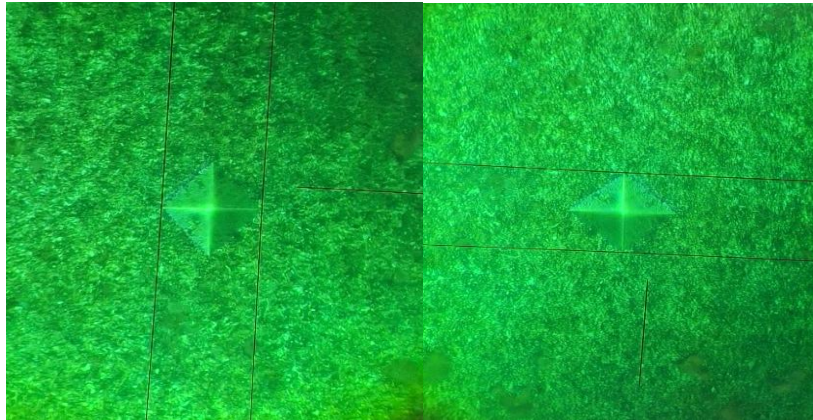


Fig 9. Vickers hardness imprints

#### 4. Conclusions

This work aims to determine the chemical composition and structural characterization of an instrument used in medical practice, through various analysis methods. Optical microscopy reveals a fine structure formed by tempering martensite (dark, slightly acicular areas) and finely dispersed carbides, with higher magnifications allowing for a more detailed identification of the carbides. These are either with fine, globular edges (secondary carbides) or with slightly polyhedral shapes in which primary carbides are recognized. At the same time, certain fine, bright networks are also observed, which belong to a small amount of residual austenite. These structural details lead to the conclusion that the steel has been subjected to a martensitic hardening and low tempering heat treatment, a secondary heat treatment specific to 200Cr120 steel. Vickers microhardness tests reveal values that fall within the usual norms for a high-grade tool steel.

The average hardness values ( $\mu\text{HV}=590\div 610$ ) are correctly associated with the structure, also attesting to the applied heat treatment in terms of mechanical properties.

#### REFERENCES

- [1]. <http://www.mortechmfg.com>
- [2]. *A. Patel, J. Pope, M. Neilson*, Design considerations for medical device manufacturers, *Biomedical Instrumentation & Technology*, Suppl. 73-75, 2012, 73-75, DOI: 10.2345/0899-8205-12.1.73.
- [3]. *A. Pascu, V. Oleksik, B. Pîrvu, A. Frăţilă, M. Ionaş, Cornel Boitor*, Modern methods of study and research in mechanical engineering applied to medicine, 5 Balkan Region Conference on Engineering and Business Education & 2nd International Conference on Engineering and Business Education, 2009, 249-254.

- [4]. *D.F. C. Moga, G. Vlădoiu, A.M. Frățilă, A.A. Dan, A.A. Dan, D. Popa, V. Oprea*, Understanding Gastric GIST: From Pathophysiology to Personalized Treatment, Vol. **13**, Iss. 14, 2024, 3997, DOI: 10.3390/jcm13143997.
- [5]. *M. Nica, B. Cretu, D. Ene, I. Antoniac, D. Gheorghita, R. Ene*, Failure Analysis of Retrieved Osteosynthesis Implants, Materials, Vol. **13**, Iss. 5, 2020, 1201, DOI: 10.3390/ma13051201.
- [6]. *A.A. Matei, I. Pencea, S.G. Stanciu, R. Hristu, I. Antoniac, E. Ciovisa, C.E. Sfat, G.A. Stanciu*, Structural characterization and adhesion appraisal of TiN and TiCN coatings deposited by CAE-PVD technique on a new carbide composite cutting tool, Journal of Adhesion Science and Technology, Vol. **29**, Iss. 23, 2015, 2576-2589, DOI: 10.1080/01694243.2015.1075857.
- [7]. *R. Marinescu, V.I. Antoniac, D.I. Stoia, D.C. Lăptoiu*, Clavicle anatomical osteosynthesis plate breakage - failure analysis report based on patient morphological parameters, Romanian journal of morphology and embryology, Vol. **58**, Iss. 2, 2017, 593-598.
- [8]. *M.A. Cordunianu, A.G. Vulcu Cordunianu, I. Antoniac, A. Luca, M. Niculescu, C.O. Chiriac, I. Corneschi, C. I. Mohor*, Experimental Analysis of a Failed Gamma Nail: A Case Report and Literature Review, Healthcare, Vol. **12**, Iss. 16, 2024, 1578, DOI: 10.3390/healthcare12161578.
- [9]. *T. F. Sonsthagen*, Veterinary Instruments and Equipment: A Pocket Guide, 2011, 1-176, ISBN 9780323072038.
- [10]. *L. Oniciu*, Coroziunea materialelor, Stiintifica si Enciclopedica, 1-264, 1986.
- [11]. *A. Porumb, S. Brito-Garcia, J. C. Mirza-Rosca, A. Fratila*, Behavior of Two Dental Alloys as Ingot and Cast Crown in Artificial Saliva, Metals, Vol. **14**, Iss. 4, 2024, 398, DOI: 10.3390/met14040398.
- [12]. *B. Ghiban, I. Bordeasu, A. Antoniac, I. Antoniac, C. M. Gheorghe, D. Bordeasu, L. M. Micu, C. Ghera, C. Salcianu, B. Florea, D. Ostoia, A. M. Fratila*, Influence of Homogenization Heat Treatments on the Mechanical, Structural, Biodegradation, and Cavitation Behavior of Some Alloys in the ZnMg(Fe) System, Crystals, Vol. **15**, Iss. 5, 2025, 458, DOI: 10.3390/cryst15050458.
- [13]. *R. Liu, J.H. Yao, Q.L. Zhang, M.X. Yao, R. Collier*, Microstructures and Hardness/Wear Performance of High-Carbon Stellite Alloys Containing Molybdenum, Metallurgical and Materials Transactions A, Vol. **46**, Iss. 12, 2015, 5504-5513, DOI:10.1007/s11661-015-3132-9.
- [14]. *J.D. Bressan, D.P. Daros, A. Sokolowski, R.A. Mesquita, C.A. Barbosa*, Influence of hardness on the wear resistance of 17-4 PH stainless steel evaluated by the pin-on-disc testing, Vol. **205**, Iss. 1-3, 2008, 353-359, DOI: 10.1016/j.jmatprotec.2007.11.251.
- [15]. *N. Hassan, A. Robu, R. Ciocoiu, I. Antoniac, R. Dumitrescu, D. Neculescu, S. Ciuca, A. Fratila*, Evaluation of surface properties in 316l stainless steel orthopedic implants, UPB Scientific Bulletin, Series B: Chemistry and Materials Science, Vol. **87**, Iss. 2, 2025, 187-200.
- [16]. *C.I. Tatia, M.M. Iancu, A. Antoniac, A. Neculescu, A. Robu, M.L. Vasilescu, I. Corneschi, A.M. Fratila*, Comparative Analysis of the Surface Properties of Different Dental Implants, UPB Scientific Bulletin, Series B Chemistry and Materials Science, Vol. **86**, Iss. 4, 2024, 245-256.
- [17]. *K. Vickery, H. Hu, A.S. Jacombs, D.A. Bradshaw, A. K. Deva*, A review of bacterial biofilms and their role in device-associated infection, Healthcare infection, Vol. **18**, Iss. 2, 2013, 61-66, DOI: 10.1071/HI12059.
- [18]. *D. J. Maggs, P. E. Miller, R. Ofri, D. H. Slatter*, Slatter's fundamentals of veterinary ophthalmology, 118, 2008.

- [19]. *M. H. Bilsky, T. W. Vitaz, P. J. Boland, M. S. Bains, V. Rajaraman, V.W. Rusch*, Surgical treatment of superior sulcus tumors with spinal and brachial plexus involvement, *Journal of Neurosurgery*, Vol. **97**, Iss. 3, 2002, 301–309, DOI: 10.3171/spi.2002.97.3.0301
- [20]. *C. Iavazzo, I.D. Gkegkes, E.K. Vouloumanou, I. Mamais, G. Peppas, M.E. Falagas*, Sutures versus staples for the management of surgical wounds: a meta-analysis of randomized controlled trials, *American Surgeon*, Vol. **77**, Iss. 9, 2011, 1206-1221, DOI:10.1177/000313481107700935.