SURFACE MODIFICATION OF METAL IMPLANTS WITH PLASMA SPRAYED LAYERS

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ABSTRACT

The individual human organism can be seen as a bio-mechanical system. To increase the lifetime of biologically integrated human implants the simultaneous improvement of bulk and surface properties is highly desired, tailoring the properties. The surface properties can be completely changed using plasma spraying. The spraying technology of human implants has to meet three main requirements: suitable surface roughness and bio-inert or bio-active chemical features for reliable osseointegration moreover strong layer stability. This paper shows the unique principles of plasma spraying and the activity of the Department of Vehicle Manufacturing and Repairing in the field of plasma spraying of human implants.

1. INTRODUCTION

Surface engineering showed a big improvement in the field of material technology during the last 15 years [2, 3, 4, 8]. Numerous metals and alloys are used as biomedical implant materials in the human body. Corrosion resistant steels and various types of biocompatible titanium alloys [1] play important roles among these materials. In order to increase osseointegration and reliability these implants are covered with different bioceramic coatings. The high energy density technologies such as plasma spraying and various laser processings, are powerful methods for suitable surface modification of machine parts such as implants.

Plasma spraying is the most generally applicable and continuously developing thermal spraying technology for the high quality of sprayed layers [7]. Applying this technology, a surface layer of arbitrary composition can be produced on a solid-state target object (Fig.1.). The original form of the coating material is powder. The developed layer thickness is a tenth of a millimeter. Technique and technology of plasma spraying depend on the function, shape and material of the target object together with the material and the structure of sprayed powder.

2. PRINCIPLES OF PLASMA SPRAYING

In ideal plasma state the electrons are free from the atomic nucleus. But practically there is a continuous recombination between ions and electrons which is characteristic for the current conditions. Plasma retains many of the properties of non-ionized gases and behaves according to the physical laws valid for gases. The main difference between them is their responses to electromagnetic forces. [1, 3]

Thermal plasmas usually have electric origin. Plasma for material processing applications is produced in a device known as plasma torch or plasmatron or simply plasma gun. This converts electrical energy into the thermal energy of the plasma gas. A direct current arc is struck between the cathode, which is typically made of tungsten, and a strongly cooled nozzle anode made of copper (see Fig 1.). Because of the aggressive erosion the life time of the cathode is limited. The main classifying factor for gases is the number of the nuclei. For example from the most commonly used gases the first nucleus contains argon and helium and the second hydrogen and nitrogen. The used mix of these gases is applied for the generating of the plasma beam (e.g. $Ar+H_2$).

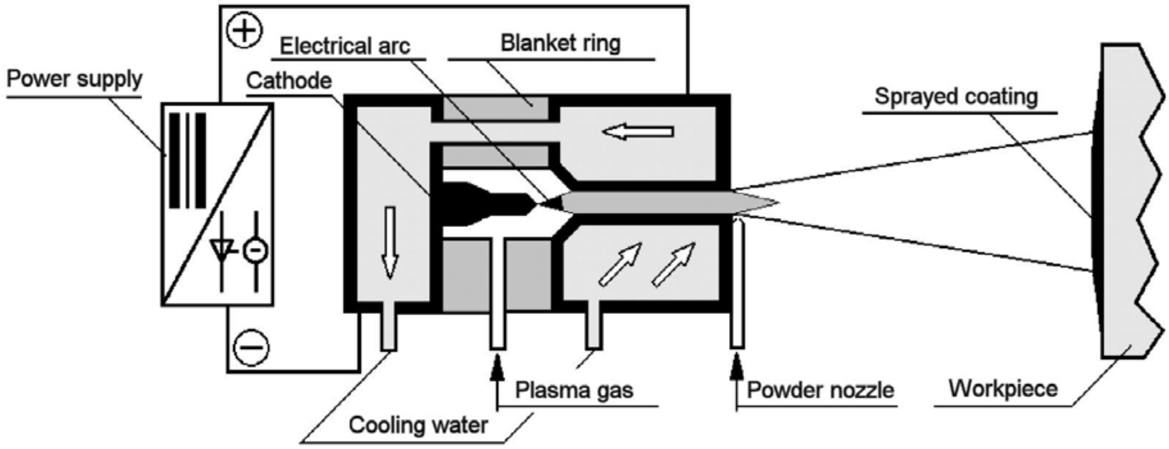


Fig. 1. The scheme of plasma spraying process [3]

The plasma gas is forced into the inter-electrode region where ionization occurs. The gas extracts energy from the arc and emerges out of the anode nozzle as a high temperature and high velocity jet [2, 4]. With industrial plasmas 6000-20000 K is reached. Fig. 2. represents the typical temperature and velocity gradients of the plasma beam.

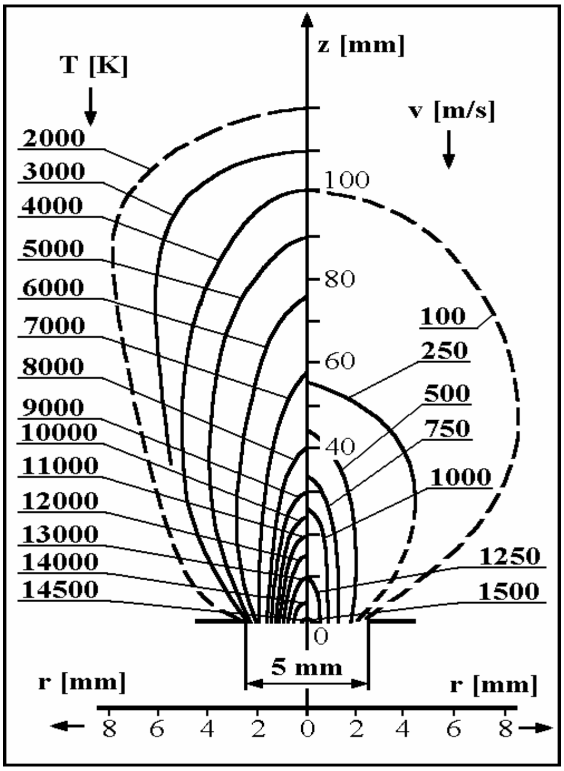


Fig. 2. The gradients of temperature and velocity in the plasma beam [8]

The unique feature of the plasma jet, that distinguishes it from other conventional oxy-fuel heat sources is its 10-100 times higher energy density. The high temperature and speed allow the depositing of an unlimited variety of alloys, inter-metallic or ceramics onto a substrate surface resulting tailored surface properties. Although the plasma temperature may be over 10000 K the substrate temperature can be kept below 400 K with air cooling avoiding the risk of substrate damage. The powder of the sprayed material is injected into the plasma beam by a powder nozzle which is situated directly in the vicinity of the exit hole of the gun. After the grains reach the surface of the substrate their solidification occurs in 0,1s. [2]

The spraying can be performed in atmospheric conditions or in a vacuum-cabin. The latter method leads to better layer properties but it needs more complicated devices. We performed our examinations by an atmospheric system.

Plasma spraying combines particle melting, rapid solidification and consolidation in a single, one-step process. Unique surface properties can be properly produced according to the dependency to be resistant for example against thermal-, wear-, corrosion-, chemical or biological effects.

There are several factors that influence the demanded coating features. Such usually important properties are coating density and surface porosity, adhesion, wear resistance, hardness and layer thickness. In general, adhesion between substrate and coating is always recommended to be strong. On the other hand the goal and priorities in connection to the density, porosity and mechanical features can be different according to the application. For this reason the technique and the technology of plasma spraying depend on the function, shape and material of the target object together with material and structure of sprayed powder.

Two essential groups of factors can be distinguished that influence the coating character. Firstly, the material and the quality of the powder and the target object basically influences most of the properties of the deposited layer. Secondly, technological parameters, for example arc voltage, current, pressure and material of gas, nozzle geometry, substrate cooling intensity, traverse speed and spraying distance determine the streaming and thermal properties of the plasma torch that carries and heats the sprayed grains.

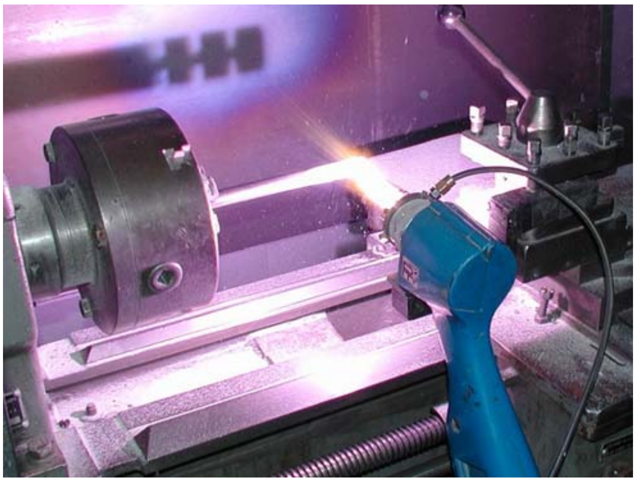
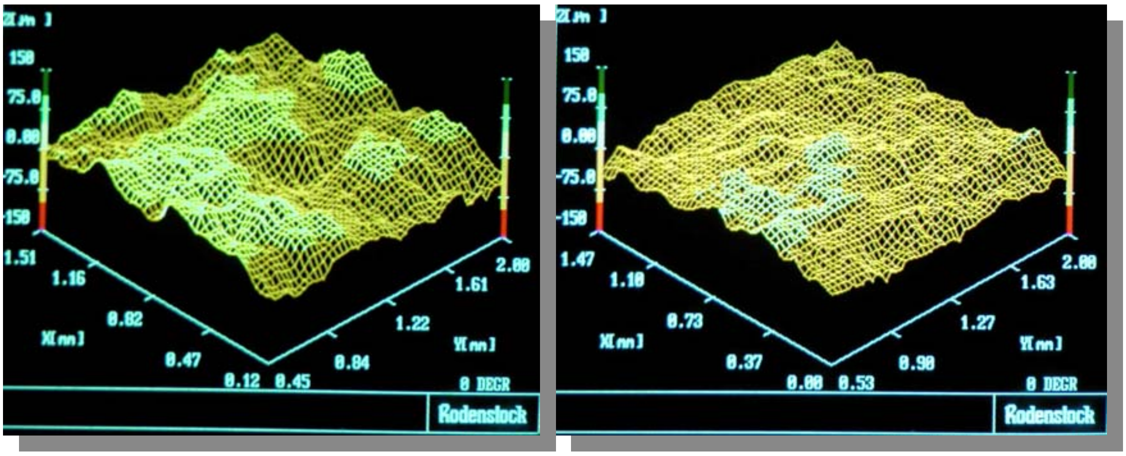


Fig. 3. Photograph of experimental plasma spraying

3. INCREASING THE BIOLOGICAL INTEGRITY OF HUMAN IMPLANTS BY PLASMA SPRAYING

The central problem of the bio-implants is associated with their duration and with the possible undesirable response of surrounding tissues to the implanted material. The complex interaction arises from the biochemical activity of the surrounding tissues. Enhanced degradation of the functional interfaces or possible simultaneous toxicities in the organism can result. Occurring toxicities and degradation of interface is avoidable by applying plasma sprayed bio-inert or bio-active implant coating. Chemical compatibility of the coating is determined by the material properties of sprayed layer. For this reason pure alumina, titaniumdioxide and hydroxiapatite was deposited on model implants in experiments respectively. These materials are not toxic and good bond strength can be achieved on usual implant base materials e.g. TiAl6V4.

The most important properties of a powder independent from its material are the size and the shape of the particles. According to the opinion of surgeons larger pores (around 300 µm diameter and depth) are desired for good implant integrity. In our researches we examined the influence of grain size on layer porosity. Generally, larger particles compose increased porosity than smaller ones. Fig. 4. shows this phenomenon, the surfaces were tested with a Rodenstock RM600 laser topograph, sprayed material was alumina on TiAl6V4.



Grain size: 200..250 µm 50..70 µm

Fig. 4. Photograph of experimental plasma spraying

Fig. 5. represents the typical size distribution of TiO_2 (grey in the plasma-coated part) the photograph of the human implant as well as the materiograph of the deposited layer on the implant surface. In Fig. 6. two Al_2O_3 powders with different grain sizes and the coatings they created can be seen. The shape of grains has influence on the behaviour of the particle in the torch as well on the density of the layer. The coatings composed of spherical powders have good characteristics of microstructure (i.e. good structural integrity) and adequate strength test results. Figures 7. and 8. shows round and angled lamellar in shape powder particles and the photograph of the deposited layers.

The most important parameters of experiments:

The basic materials:	— BIOLAN;
	— Titan 99,99;
	— $TiAl_6V_4$
The materials of powders:	— Al_2O_3,
	— TiO_2,
	— Hidroxyapatite $Ca_5(PO_4)_3OH$ (different types of grains).
Steps of technology:	— Preparation of selected surfaces (local bonding of surfaces with shadows material),
	— Cleaning,
	— Al_2O_3 blasting (increasing the adhesion ability).

Main parameters of the plasma spraying process:

— Power:	30	kW
— Sprayed powder volume:	40÷50	g/min
— Spraying distance:	120	mm

The average results of mechanical tests were:

		TiO_2	$Ca_5(PO_4)_3OH$
Tensile strength	R_m	≈ 17 MPa	≈ 7 MPa
Shear strength	τ	≈ 4÷7 Mpa	≈ 4÷7 MPa

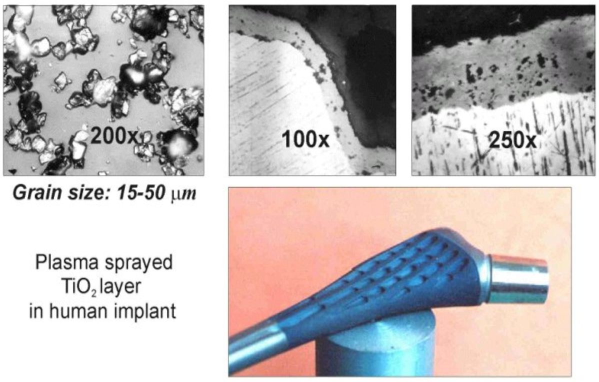


Fig. 5. TiO_2 sprayed human implant and materiographical structure of the layer

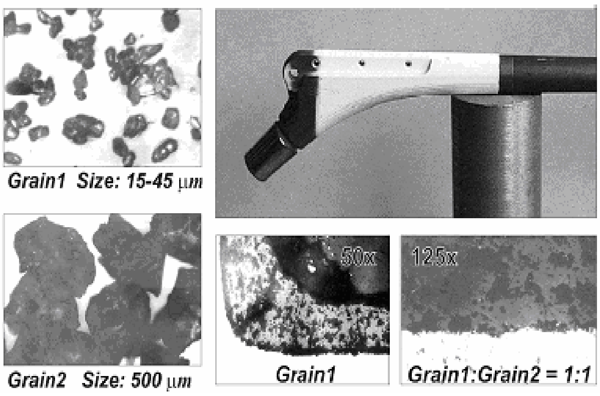


Fig. 6. Alumina sprayed human implant and materiographical structure of the layer

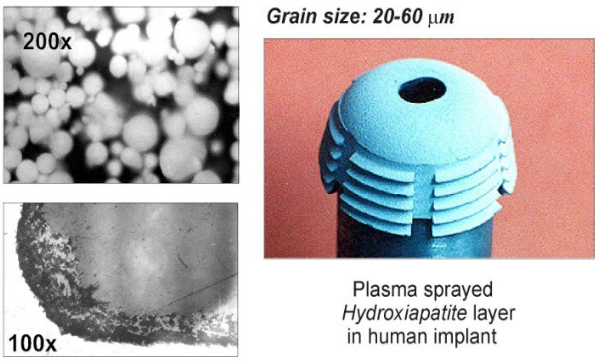


Fig. 7. Hydroxiapatite sprayed human implant and materiographical structure of the layer (spherical grains)

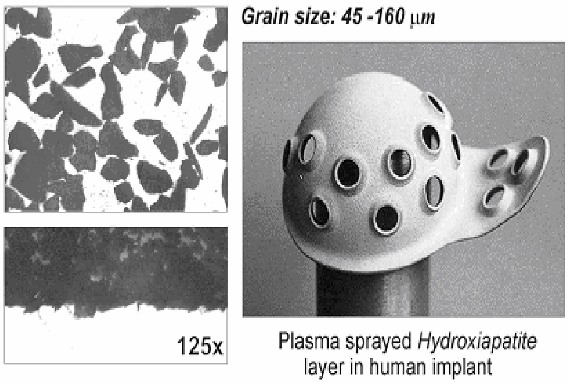


Fig. 8. Hydroxiapatite sprayed human implant and materiographical structure of the layer (elongated grains)

CONCLUSION

The most important parameters are the quality and lifetime of the implants used in human body. Surface coatings on human implants can play important role in the biological integration of foreign material into the bone. Chemical properties of (coating) material, surface porosity and layer stability act together on durability of interface of bone and implant.

REFERENCES

[1] Pinke, P., Zitnansky, M., Caplovic, L., Réger, M.: Biocompatible titanium alloys, First Hungarian Conference on Biomechanics, Budapest, June 11-12, 2004, ISBN 963 420 799 5, pp. 374-382.

[2] C. Suryanarayama (1999.): Non-equilibrium Processing of Materials Pergamon 1999., ISBN 0 08 042697 2, pp.: 122-179.

[3] J. Takács, A. Lovas, J. Berzy, A. Sklánitz, A. Szilágyi (2003.): Advanced Materials In The Recent Development of Bioengineering, Research News BME 2003/1, ISSN 1586-6270, p.: 42.

[4] D. Matejka, B. Benko (1989.): Plasma Spraying of Metallic and Ceramic Materials - John&Sons Ltd, Baffins Lane, Chicester, West Sussex, UK 1989., ISBN 0 471 918768, p.: 280.
[5] Takács, J., Buza, G., Bakondi, K. (1994.): High power density technologies modifying the surface properties. EUROMAT '94. TOPICAL Conference, Balatonszéplak, 1994. pp.: 472-477.
[6] Bakondi, K., Buza, G., Kiss, Gy., Takács, J. (1991.): A plazma porszórás alapjai, lehetőségei. Bányászati - Kohászati Lapok, Kohászat, Budapest, 124.évf. 1991.10.sz. pp.: 419-423.
[7] Takács, J. (1999.): High Energy Technologies for the Surface Engineering of Light Alloys (Invited), Proc. of Heat Treatment and Surface Engineering of Light Alloys, 7-th Int. Seminar of IFHT (Edited: Lendvai J., Réti T.) GTE, Budapest, 1999. sept. 15-17. pp.:111-120.
[8] Takács J. (2004.): Korszerű anyagok a felületi tulajdonságok javításában – Műegyetemi Kiadó, 2003.

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