ISSN 1330-3651
UDC/UDK 621.9.044.4:591.471.3

PRELIMINARY RESULTS OF EXPERIMENTAL CUTTING OF PORCINE BONES BY ABRASIVE WATERJET

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Professional paper

The abrasive waterjet (AWJ) cutting is currently applied to a wide range of materials; thus, this technology is implemented in different kinds of techniques. A priority benefit of this technology includes the absence of thermal effect on the workpiece. This is the reason why the AWJ is being extensively applied not only in many types of industry, but also in medicine. Possibilities of its further use however have not yet finished. One of the areas in which this technology is in the beginning is orthopaedic surgery. In order to implement this cutting technique, the experimental cutting of porcine bones "ex vivo" were performed. The surfaces created by waterjet were measured by a contact profilometer in order to quantify the surface profile parameters *Ra*, *Rq* and *Rz*. These experiments represent the first step of the authors in implementing the abrasive waterjet cutting technology into the orthopaedic surgery.

Keywords: *abrasive waterjet cutting, porcine bones, surface quality*

Preliminarni rezultati eksperimentalnog rezanja svinjske kosti abrazivnim vodenim mlazom

Stručni rad

Rezanje abrazivnim mlazom vode danas se primjenjuje za širok spektar materijala, stoga se ova tehnologija implementira u različitim granama tehnike. Prioritetna korist ove tehnologije je odsutnost toplinskih utjecaja pri rezanju radnog komada. To je razlog zašto se ova tehnologija počinje primjenjivati ne samo u industriji, nego i u medicini. No, mogućnosti daljnje primjene rezanja abrazivnim vodenim mlazom još uvijek nisu završene. Jedno od područja gdje je primjena te tehnologije još uvijek na početku, jest ortopedska kirurgija. U cilju implementiranja ove tehnike rezanja, provedeno je eksperimentalno rezanje svinjske kosti "ex vivo". Dobivene površine su mjerene kontaktnim profilometrom, kako bi se odredile vrijednosti parametara hrapavosti *Ra*, *Rq* i *Rz*. Ovaj eksperiment predstavlja prvi korak autora u mogućoj primjeni tehnike rezanja vodenim abrazivnim mlazom u ortopedskoj kirurgiji.

Ključne riječi: *abrazivni vodeni mlaz, kvaliteta površine, svinjske kosti*

1 Introduction
Uvod

The first medical applications of this technology were published in the eighties of the last century [1], when a jet of water [6, 7, 8, 9] was used for cutting soft tissues [1, 2]. There are currently no available relevant studies exploring in detail the use of abrasive waterjet cutting in orthopaedic surgery for the implantation and re-implantation of total hip and for knee replacement [4, 5]. The goal of this experimental research is to get a deeper comprehensive insight into the issue of identification and analysis of factors in relation to the surface topography of bone tissue. Achieving the desired surface quality is of great importance for the functional behaviour of a part.

2 State-of-the-art
Prikaz stanja

Bone is a complex biomaterial [5] that from a mechanical point of view shows different mechanical properties according to its structure, location, direction of loading, load history and exhibits typical structural inhomogeneity and anisotropy. Bone tissue is formed by cells and extracellular matrix with minerals. Bone is made up of spongy and compact tissues. Bone cells produce amorphous and fibrous extracellular matrix. Biomechanical properties of bone tissue are primarily the collagen matrix and minerals. Collagen fibres can resist tension, but for other methods of loading are elastic. Minerals, primarily calcium in the form of hydroxyapatite can provide hardness and brittleness. Therefore demineralized bone is soft and supple. Bone cutting techniques, as we know today, date back to the 17th or 18th century. Tools used in surgery were chisels, toothed saws, knives, and were copies of tools used in wood industry [8]. The surgeons' tools included only a few technical improvements compared with those commonly used for cutting other materials.

As the abrasive waterjet cutting has no thermal effect, it is suitable for applications where the structural change of material is inadmissible. In medical applications critical temperature is much lower than in industrial uses. This issue was studied by [2]. The authors dealt with the abrasive waterjet cutting of bones. Bones are sensitive to heat. Tissue damage is dependent on temperature and time of exposure. The damage is already irreversible in the time of about 10 seconds at the temperature of 57 °C when there is necrosis and inadequate bone healing [3]. Despite the notable contribution of research in this field, current practice requires a more detailed characterization and description of tool interaction with bone tissue. Complying with strict conditions in the operational environment, it is possible to use this technology for various surgical interventions [10]. Conventional tools (such as saws and milling machines) can cause thermal damage to bone tissue.

Knowledge gained from experimental studies will help not only to effectively assess the surface quality, but will serve as a basis for the applications of abrasive waterjet cutting in orthopaedic surgery.

3 Experimental conditions
Eksperimentalni uvjeti

Experiments were carried out under the academic cooperation among the Faculty of Manufacturing Technologies in Košice with a seat in Prešov, Institute of Physics, HGF, VSB - TU Ostrava, Faculty of health professions Prešov University, University Hospital J. A. Reimana in Prešov, Mechanical Engineering Faculty in Slavonski Brod and allowed to administer Academy of Sciences of the Czech Republic in Ostrava. Detailed experimental conditions are given below in Tab. 1.

***Table 1** Experimental conditions*
***Tablica 1.** Eksperimentalni uvjeti*

Factors	Experimental runs	
	1	**2**
Pressure, p /MPa	300	
Traverse rate, v /mm/min	10	30
Abrasive mass flow rate, m_a /g/min	-	50
Orifice, d_o /mm	0,33	
Focusing tube, d_f /mm	0,8	
Focusing tube lenght, l_f /mm	72	
Standoff, z /mm	3	
Number of passes	1	
Cutting head angle, φ /°	90°	
Cutting direction	radial	
Abrasive	-	Barton Garnet
MESH	-	80

The adjustable cutting table from PTV company, designed for surface application of the abrasive waterjet technology was used. The water pressure was generated by the pump PTV-37-60 with Q = 4,7 l/min with a power P = 60 HP. The technological head from PTV Company was used. All samples were produced with a constant set of input factors (Tab. 1). Experiments were carried out under strict sterile conditions. At the first stage, the experimental section cut was performed without abrasive water jet (Tab. 1, sample 1). The surfaces of the porcine bones (sample 2) were created by AWJ cutting with a constant abrasive mass flow rate m_a = 50 g/min. The samples were created in radial direction. The following Fig. 1 shows the experimental procedures of cutting the bone tissue. The first experimental technique without a constant standoff distance was performed by instinct. A team of researchers conducted a series of experiments in order to prepare the bone for titanium knee arthroplasty. Due to flexible nature of the abrasive waterjet [11, 12], we tried to achieve the maximum smooth surface during the experimental testing. When cutting the porcine bones with a high-speed waterjet, some irregularities occur. Those are used for further processing in order to evaluate the surface roughness. The surface quality of each sample was measured by the contact surface roughness profilometer Mitutoyo 401, along 4 geometrical depth traces h (mm) on sample 1 and 11 geometrical depth traces h (mm) on sample 2 (Fig. 2c). Measurements were performed till the waviness on surface occurred. According to the outputs obtained from Scirus database, a few theoretical and experimental studies on the surface profile and roughness of machined bones were reported. One study was published by Schwieger et al. who conducted the experimental testing of bone cuts that were assessed by the accuracy and biological potency of the cut surfaces.

Fig. 2b shows an example of experimental measured surface of the sample where the technological head was conducted by a pineal gland distal (lower extended end) through the bone (ossis femoris), which consists of two joint ridges. These are condylus medialis (inner bump) and condylus lateralis (outer hump) between them is the fossa supracondylaris.

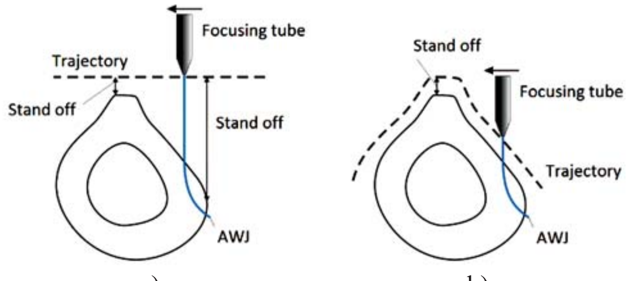

***Figure 1** Schematic representation of the AWJ cutting technology during experimental cutting: a) implemented in Hannover* [2], *b) realized at the Institute of Geonics in Ostrava - Poruba*
***Slika 1.** Shematski prikaz AWJ tehnologije rezanja za vrijeme eksperimenta: a) implementirano u Hannoveru* [2], *b) ostvareno na Institute of Geonics u Ostravi - Poruba*

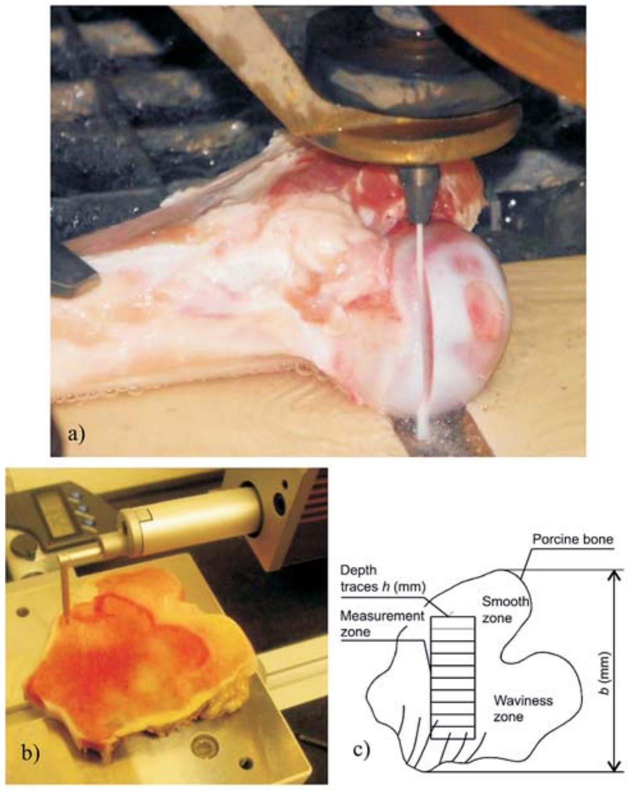

***Figure 2** a) Experimental cutting of porcine bones, b) surface roughness measurement by Mitutoyo 401, c) measurement traces h (mm)*
***Slika 2.** a) Eksperimentalno rezanje svinjske kosti, b) površinska hrapavost mjerena pomoću uređaja Mitutoyo 401, c) mjerenje tragova h (mm)*

4 Results and discussions
Rezultati i rasprava

It is possible to clearly distinguish each area of the samples, such as entrance section, section area and exit section. The surfaces being created by abrasive waterjet show specific geometry due to different technological conditions. Technological conditions have a significant impact on the physical and mechanical interactions of abrasive waterjet with a target material and also on the overall surface morphology. The topographic surface structure reflects technological properties of the hydrodynamic cutting tool. The following figure shows the values of surface roughness parameters Ra, Rq and Rz being measured in the radial direction. The conditions of the experiment are given in Tab. 1. and Fig. 3.

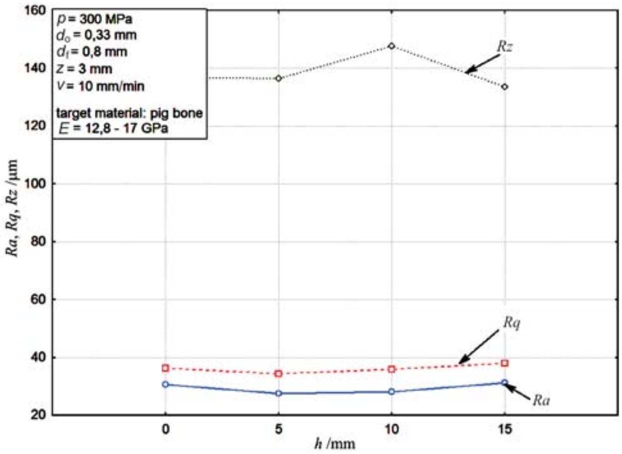

Figure 3 *Plot of surface roughness profile parameters Ra, Rq and Rz measured at four measured traces h (mm)*
Slika 3. *Parametri profila površinske hrapavosti Ra, Rq i Rz mjereni na četiri mjerna traga h (mm)*

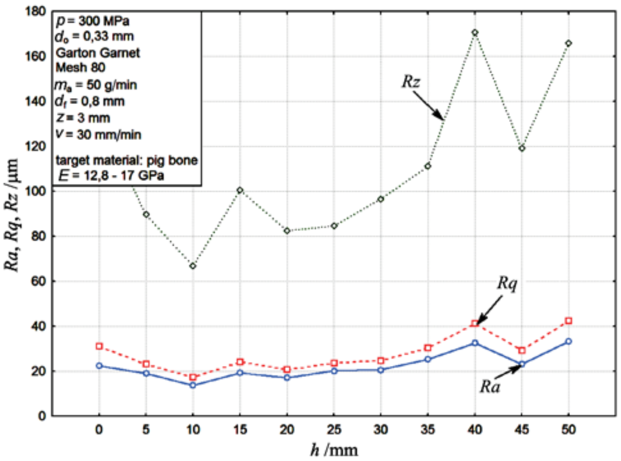

Figure 4 *Plot of surface roughness profile parameters Ra, Rq and Rz measured at eleven measured traces h (mm)*
Slika 4. *Parametri profila površinske hrapavosti Ra, Rq i Rz mjereni na jedanaest mjernih tragova h (mm)*

The relatively high levels of surface profile parameters were found at the beginning of the separation cut (Fig. 4) (1-2 mm depth of the separation cut), where the rigidity of the tool is high, but its penetration into bone tissue is energetically demanding what can indicate the presence of the initiation zone. As it can be seen from the results of these measurements, the surface roughness parameter *Ra* is below 40 µm at a measured trace $h = 40$ mm and $h = 50$ mm. Further research needs to be done to find clinically usable abrasive materials and also their experimental verification in cutting of bone tissue.

5 Conclusion
Zaključak

The preliminary results of experimental cutting of porcine bones by abrasive waterjet cutting are presented in this paper. The tissue of bone cutting used to be a long term problem for surgeons. The analysis of the effects of this technology was carried out here. The surfaces created by abrasive waterjet cutting were assessed using surface profile parameters *Ra*, *Rq* and *Rz*. It has been found that the surface quality of bones is suitable for orthopaedic surgery procedures such as total hip and knee replacement or for osteotomies. Further research will focus on the impact of abrasive waterjet factors on the surface quality of bones. The ongoing problems are in finding a biocompatible abrasive material that could improve the efficiency of this technology and is environmentally friendly.

Acknowledgement
Zahvala

Experiments were carried out under the project for the support of science and research (RRC/03/2010), ASCR No. AV0Z30860518 and VEGA 1/0972/11.

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