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The Analysis of the Accuracy of Wax Casting Models for Medical Applications

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Abstract

The article presents an analysis of the dimensional accuracy of wax models, made by Vacuum Casting Method (VC), used in the manufacturing process of bone defects implants of the skull vault. Silicone molds were made on the basis of Rapid Prototypes (RP) models. The RP prototypes were created from 3D-CAD (CATIA V5) developed during studies of the shape of the cranial vault bone defects. The technology used in the RP process was stereolithography (SLA). During the researches also were used an additional tested models. These models were designed on the basis of the dome with cutouts of different shapes. The measurement process was conducted by optical coordinate measuring system. The research was carried out using an Atos Triple Scan scanner. The analysis presents that there is a possibility of using the technology of Vacuum Casting wax models in silicon molds, as the indirect method in the process of implementation of the implant-bone of the skull cap.

Keywords: Innovative Foundry Materials and Technologies, Reverse Engineering, Rapid Prototyping, Vacuum Casting, Optical Coordinate Measuring Systems.

1. Introduction

Development of the measurement and diagnostic methods in conjunction with the CAD/CAM systems has allowed the introduction of innovative solutions for new treatments.

Diagnostic measurement techniques used in medicine, for example Computer Tomography (CT), allow to get images of tissue structures in the form of three-dimensional numerical models. On this basis it is possible to produce, inter alia, using the Rapid Prototyping techniques (RP), different types of individual implants, simulation models or templates [1,2,3,4].

From the standpoint of medical applications, it is important to pay attention to the biocompatibility of the material of the prototype, which directly affects the success of the reconstruction [5]. At the present moment, most of the materials used in the RP technologies does not satisfy this condition. In the absence of access to biocompatible materials out of the situation is the use of Rapid Tooling (RT) methods in order to implement titanium castings such as implants. In the manufacturing process of models for medical applications the indirect method which can be used is Vacuum Casting (VC). In this method, the wax models are cast in silicone molds.

To verify the dimensional accuracy of wax models obtained in the VC process was used optical scanning system ATOS Triple Scan to blue light. The researches were performed in the several series of measurement.

2. The process of the numerical and physical reconstruction of the bone implants prototypes

Reconstruction of medical numerical models is carried out in the Reverse Engineering (RE) process. It involves the transformation of a physical object to a numerical model using a coordinate measuring technique. Coordinates of points obtained from measurements are the basis for determining the geometric parameters of the object in the process of digitization [3,4,6,7].

The initial step in creating 3D models was to define the edges and contours of the object defined during the acquisition of 2D images (DICOM). In the diagnosis of skeletal was used multi-row spiral CT scanner - Siemens Sensation 10. In the next stage of research, numerical models were prepared and processed using 3D-DOCTOR program. On the basis of the 2D data were created 3D models, which next were converted to the STL model [6,7,8,10].

Based on that data it is possible to create models of the bone defects and models of the implants (Fig. 1). Modeling implants were performed in CAD systems due to the ability to add additional features to the model geometry in these systems [8,9,11].

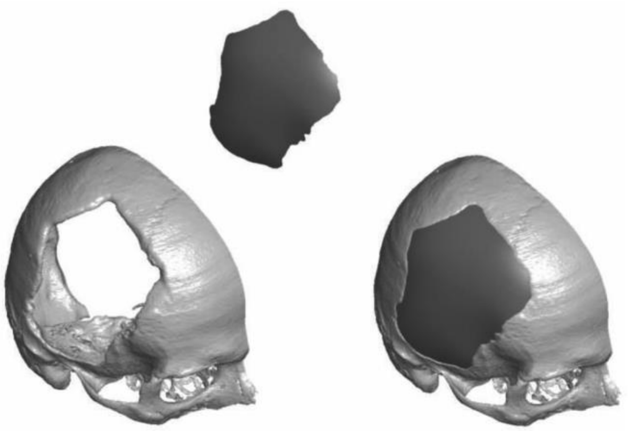

Fig. 1 3D - CAD model of the skull fragment with defect and its complement

In the next stage of the manufacturing process of the bone implants, using the Rapid Prototyping technology, the prototypes of the implants was made. For this purpose was used Stereolithography (SLA).

SLA process involves building a model layer by layer using the polymerization of the liquid resin with a laser beam (Fig. 2) [6,7,8].

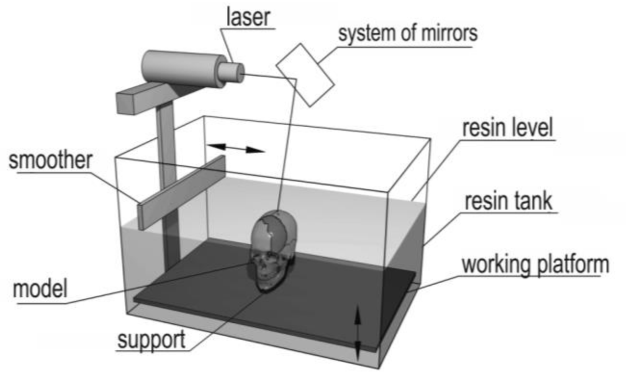

Fig. 2 Scheme of the SLA process

Models of implants were performed in Rapid Prototyping Laboratory at the Faculty of Mechanical Engineering and Aeronautics, Rzeszów University of Technology on the SLA-250 machine 3D Systems. The material used in the process was the epoxy resin SL5170 (Fig. 3).

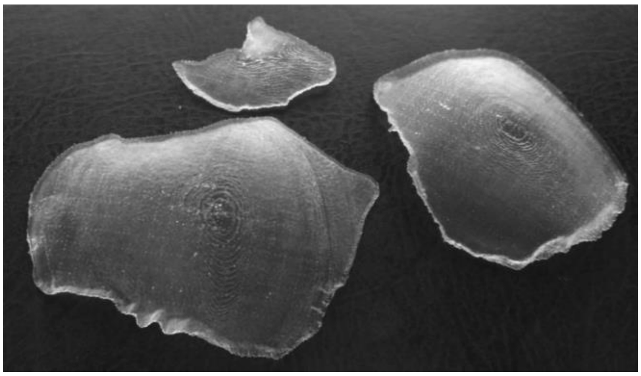

Fig. 3 Models of implants made by Stereolithography

Additionally to determine the geometrical precision of wax casts some tested models, presented on the figure 4, were made.

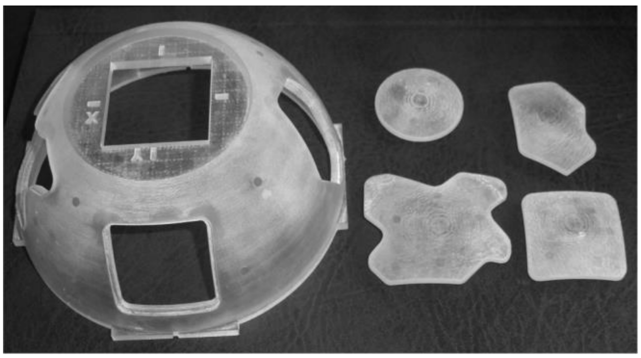

Fig. 4 Prototypes of tested models

3. Cast wax models in silicone matrices

The use of silicone matrices allows for rapid and relatively cheap production of wax models for precision casting. Durability of silicone matrices enables the execution of the several dozen models (Fig. 5). Silicone matrices were made on the basis of models presented in Chapter 2. This matrices is a very high-quality tool for the implementation of wax models of complex shapes. Additionally should be designed delivery system of liquid material and vent channels into a mold. Silicone matrices provides adequate dimensionally-shaped stability and accurate representation of the surface of the reference model [12,13].

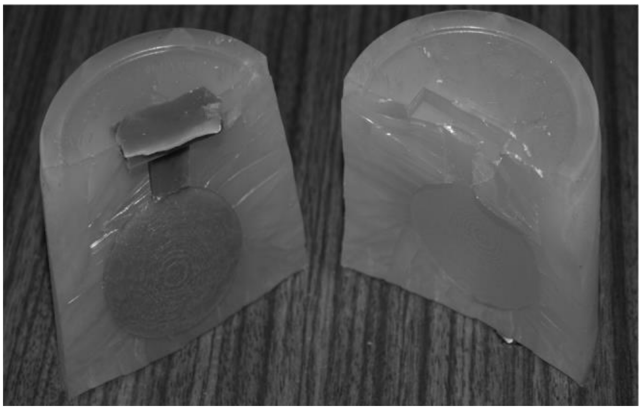

Fig. 5 Silicone matrices of model`s wax cast

The completed matrix must be properly prepared to comply with the wax model. The parts of matrix must be joined together by metal clips, a mounting tape or the form in which it was formed. Then it must be heated to a temperature of a few degrees above the melting point of the wax. Then the matrix is flooded with liquid wax and allowed to cool [12,14].

In research the waxes with different physical properties were used (Table 1).

Color of wax	Determination of wax (species)	The melting point of the wax, ° C	The temperature of the mold before pouring, ° C	The heating time of the form, h
brown	RECLM	130	85	2
Gray-blue	Blue wax RECLM+	130	85	2
Light green	A7FR/60	140	90	2
Dark green	KC4017B	140	90	2

Tab. 1 Features of casting wax [12]

On the basis of Vacuum Casting process were obtained four sets of wax models of different shapes (Fig. 6).

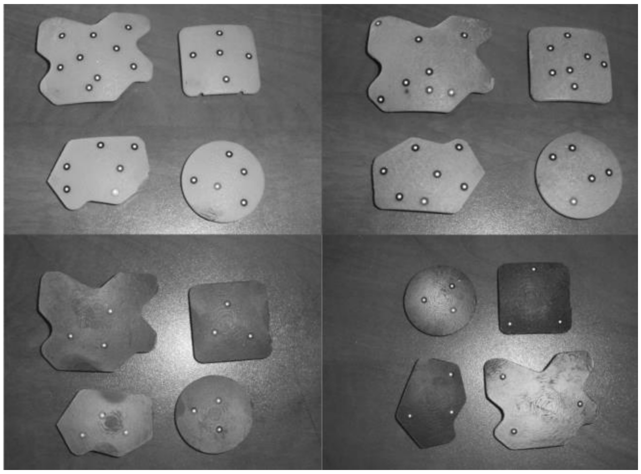

Fig. 6 The wax duplications made on the basis of the SLA models

4. The measurement of the wax models using optical system - Atos Triple Scan

The measurements of the investigate models were performed using optical measuring system ATOS Triple Scan co. GOM. The measurement data were used to verify the dimensional and shape accuracy of wax casts.

The ATOS optical system measurement uses the distortion effect a set of lines (stripes) in the form of rays of light falling on the surface of the test object and the registration of these distortions using two cameras (Fig. 7). The cameras are positioned relative to each other at a certain angle and at a predetermined distance, which allows to precisely define the 3D coordinates of the camera for each pixel based on the optical transformation equations [15,16].

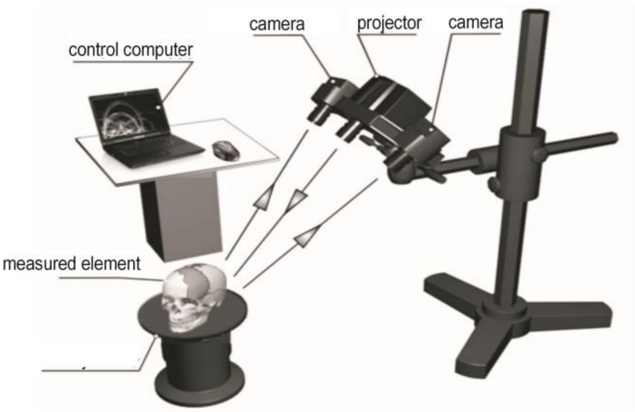

Fig. 7 Optical scanning scheme

The full data of the construction of scanned objects can be achieved by making more measurements during various settings of models relatively to the measuring head. For this purpose, the rotary table can be used which is conjugated with the measurement system. Additionally on the measuring table are located reference points. By scanning these reference points the base file is created. This file reduces the number of reference points placed on the test model, and reduce the duration of the scan (Fig. 8) [15,16].

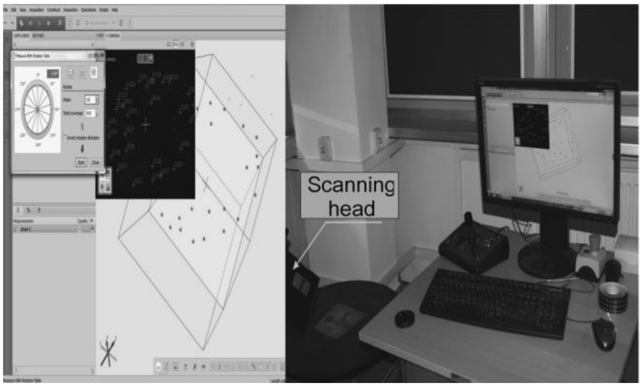

Fig. 8 Scanning reference points of the rotary table

Reference points (markers) are also positioned on the surface of the scanned element (Fig. 9). With these tags, the system automatically determines the current position of the scanner.

Sometimes there is a need to cover the scanned models with the layer of powdered chalk. It eliminates reflections of light. Powder coating layer is from 0.8 microns to 1.2 microns.

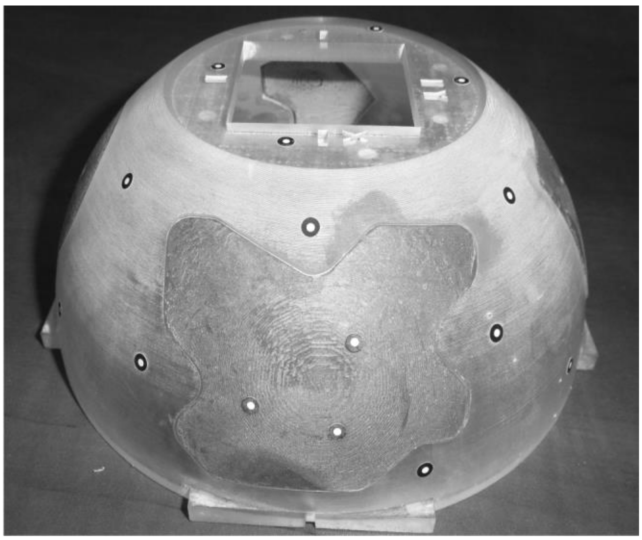

Fig. 9 Tested models with marked reference points, covered with a layer of powdered chalk

The obtained data in the subsequent stages of the measuring process are automatically combined together through the coordinate system which is created for a particular measurement process (Fig. 10).

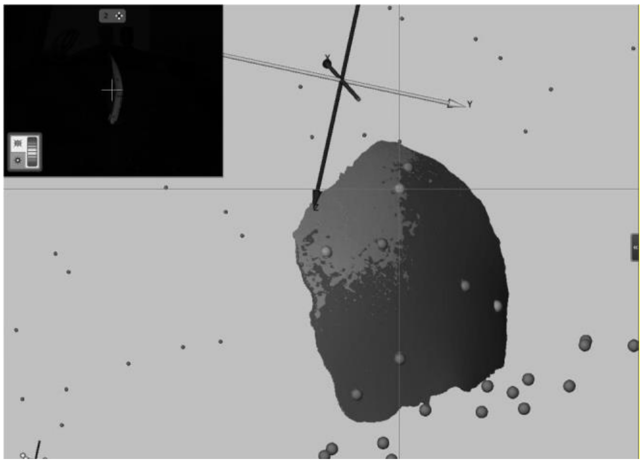

Fig. 10 Transformation single measurements into one coordinate system

The scanned surface of model is defined by millions of data points. The ATOS Professional software enables translation the received data, in a form of a set of points, into an optimized form of a triangle mesh.

The ATOS Professional software gives the possibility to import the nominal 3D-CAD model in order to conduct a comparative analysis of scanned models with their equivalent models (Fig. 11).

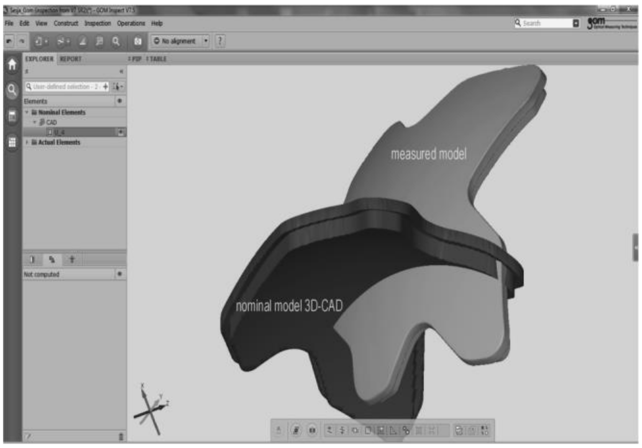

Fig. 11 The import of the nominal 3D-CAD model to the ATOS Professional software

5. The results

The verification of the accuracy of the analyzed wax castings were made at several series of measurements. At this stage, the GOM Inspect software was used which is delivered with the scanner.

Based on a comparison of the nominal 3D-CAD models acquired from measurements were obtained the information about the geometrical deviations. The selected results are presented below in the form of color maps (Fig. 12-15).

The obtained results indicate that the geometrical deviations of the tested casts are between ± 0.7 mm.

Larger deviations can be observed in the areas of surface collapse. In these zones, the deviations range of about ± 3mm. The largest occur in the case of wax models made of the A7FR/60 material.

It should be taken into consideration that the accuracy of those wax models also affects the accuracy of the implementation of RP models, which were the base of the silicone matrices in the VC process.

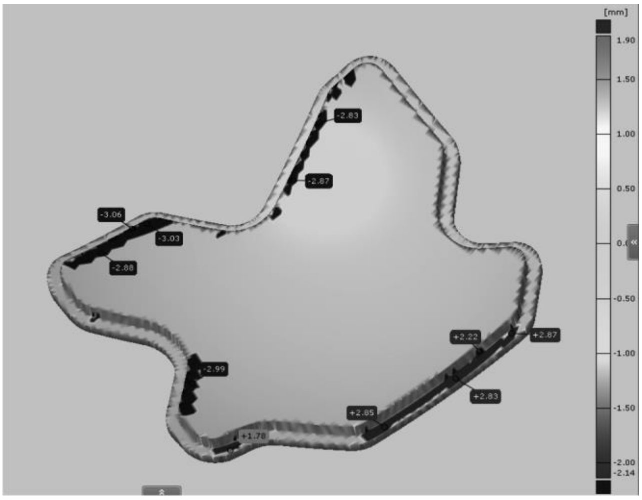

Fig. 12 The results of geometric deviations of the RECLM wax model

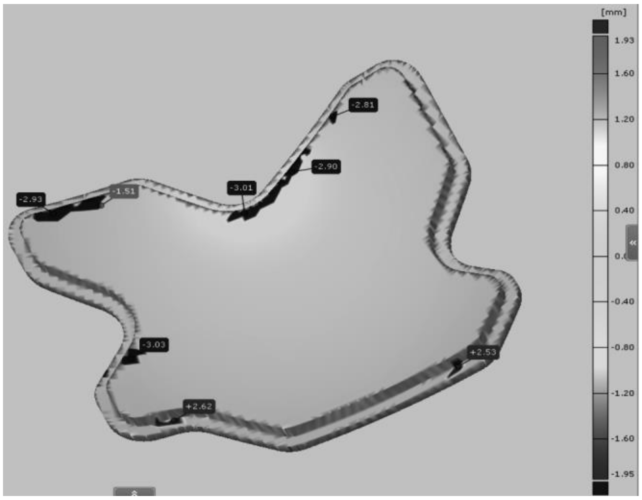

Fig. 13 The results of geometric deviations of the blue wax RECLM+ wax model

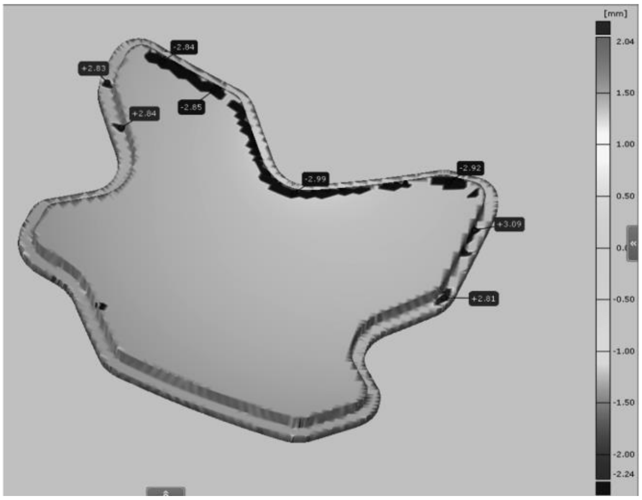

Fig. 14 The results of geometric deviations of the A7FR/60 wax model

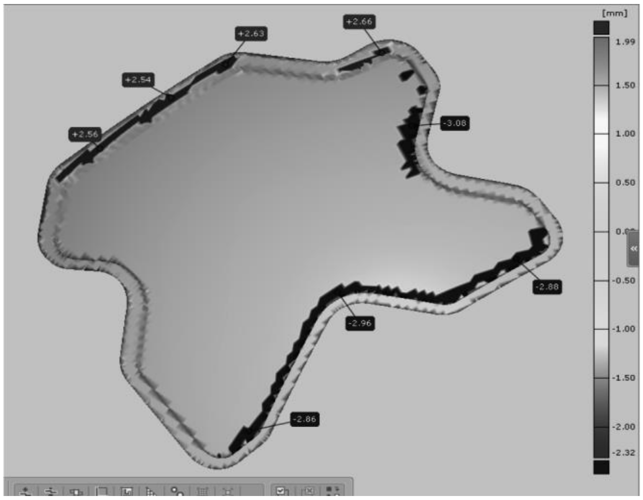

Fig.15 The results of geometric deviations of the KC4017B wax model

6. Conclusions

The research has shown that the geometrical deviations of the tested casts are between ± 0.7 mm. The areas which have the maximum deviation are located near the sharp edges and the collapse of the surface at the edges of all samples.

In order to prevent the appearance of sharp edges there is a possibility to chamfer or rounding sharp edges during the design process in CAD systems. In the case of bone defects of the skull it does not affect the functionality of the implant.

Also was found that the shape does not affect in a significant way of the accuracy of the dimensional wax casting.

The results of the study shows that the Vacuum Casting technology can be used in the preparation of cranial bone implants as an indirect method.

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