

Methods of fabrication of medical models with complex spatial structures

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Abstract

The process of creating medical models for experimental tests applying modern Rapid Prototyping methods is presented in the article. Respective Rapid Prototyping methods i.e. JS-PolyJet, Selective Laser Sintering (SLS), ProJet and Vacuum Casting (VS) methods are also characterised. The possibilities of using the above in model research and especially in photoelastic research on the examples of human skull top part and a fragment of syndesmosis of the skull are discussed. Rapid Prototyping and Rapid Tooling methods together with computer aided systems CAD/CAM make it possible to carry out numerical analysis and experimental tests on models of very complicated inside and outside shapes. RP techniques allow for fabricating medical models of a tissue structure of human skeleton bones. In case of photoelastic tests, when examined medical object can be destructed, RT techniques and precisely Vacuum Casting method allows for making medical models with reasonable prices and quantities adequate for experimental aims. There is a possibility of analyzing much bigger range of cases of loading regardless of the costs of experiment. Therefore applying Rapid Prototyping techniques for fabricating medical models allows for extending the possible applications of experimental tests in medicine.

Keywords: Innovative Foundry Technologies and Materials, Product Development, Vacuum Casting, Rapid Prototyping.

1. Introduction

For the analysis of complex medical issues beside numerical methods one can simultaneously make use of experimental tests to verify the obtained results. In case of the experimental test it is necessary to make physical models and to carry out verifying tests on them [1]. The starting point of the whole process is creating a 3D-CAD virtual model. It is then changed into a physical model by means of Rapid Prototyping incremental techniques. This model can be a basis for making casting forms by means of VC (Vacuum Casting) method. This method makes it possible to create a greater number of ready models using cheaper materials [2]. It is especially important in case of fatigue experimental tests where there is a great probability of destroying the model. An

example of these kind of tests can be photoelastic where the tested model is permanently damaged regardless of the applied method.

2. Rapid Prototyping methods

The first stage in Rapid Prototyping methods is preparing 3D-CAD model usually in STL format. This kind of model is processed to become a set of data appropriate for RP systems. Incremental shaping consists in dividing the model into horizontal layers. The layers are then used in an appropriate order to build ready physical model. The way of making the subsequent layers is contingent on the applied method. The next fragment of the paper enumerates the Rapid Prototyping methods which were used to create the medical models of human skull and a fragment of syndesmosis of the skull.

2.1. SLA method

In Stereolithography (SLA) a model is created by photo polymerization of liquid resin hardened by means of laser beam. After checking the data accuracy of the model recorded in STL format, the elements are disposed in the working space and technological supports are selected using 3D Lightyear program. If possible one should go by a rule of arraying the model in such way that the largest number of complex intersections is placed horizontally. It is caused by higher resolution of the device in horizontal plane and is especially significant while modelling complex unbounded surfaces. The contour lines, after adjusting technological parameters of the process, are transformed into files which control work of the device. The SLA model is created layer by layer on the basis of them. This method can be applied for fabricating models with complex inner structure which is especially significant in case of tests carried out on medical models [3,4,5]. The 1:1 models of human skull top part was made with SLA 250 device (fig. 1) at The Faculty of Mechanical Engineering at Rzeszów University of Technology. The material used is SL 5170 epoxy resin. The ready model of skull's top part is shown in figure 2.



Fig. 1. Stereolithography device - SLA 250/50 (Rzeszow University of Technology)



Fig. 2. The 1:1 scale model of a human skull made with SLA method

2.2. JS-PolyJet method

In this method photohardenable resins is applied layer by layer. Each layer is separately hardened with UV light radiated by a lamp integrated with printing head. A model of a fragment of cranial syndesmosis on a scale of 3:1 was made of FullCure 720 resin which enables to obtain great accuracy and stiffness. EDEN 350 device in Bibus Menos company was used for making the model. The device allows for obtaining accuracy within a range of 0,1=0,2 mm. Similarly to SLA method, models of complex inner structure can be fabricated with this method (fig. 3).

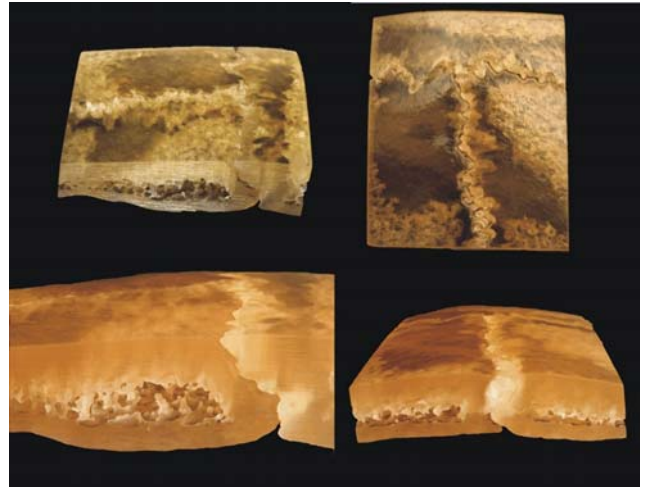


Fig. 3. A model of cranial syndesmosis fabricated with JS – PolyJet method

2.3. SLS method

The method of Selective Laser Sintering (SLS) of powder consists in hardening the surface of the powder layers by means of laser beam. The sintering process is performed in a chamber filled with powder where a platform together with the fabricated model lowers down by a value which equals the layer's thickness. Hardening of subsequent layers causes partial melting of the previous layer which makes it possible to obtain coherent model structure. During the sintering process the model is dipped in the powder and that is why it is not necessary to apply additional supportive structures. The models of skull on a scale of 2:1 (fig. 4) was made with SLS EOS Formiga P100 device in Bibus Menos company. The applied material was PA2200 polyamide powder. The syndesmosis fragment is presented in figure 5.



Fig. 4. Models of skull fabricated with SLS method

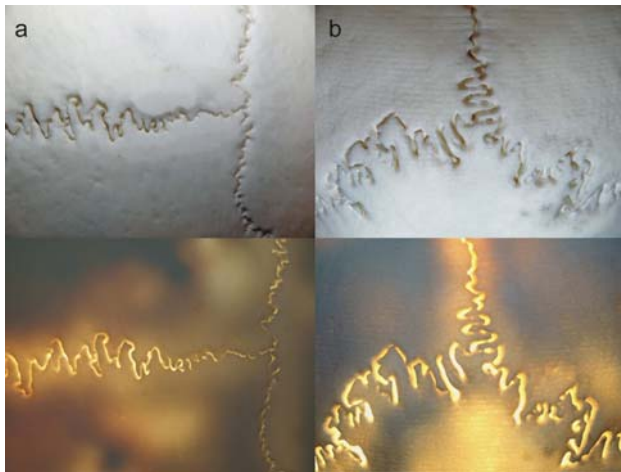


Fig. 5. Fragments of syndesmosis made with SLS method

2.4. ProJet method

In this method layers of liquid wax are applied with a printing head. The wax is hardened by UV rays. The modelling material VisiJet CPX200 was used as the wax and the supporting material was VisiJet S200. The supporting material is more brittle in comparison to the modelling material and it has lower melting temperature (about 45°C) which allows for removing the supports by means of thermal method. This method allows for obtaining great accuracy of the order of $0,025 \div 0,05$ mm for each printed centimetre. The accuracy depends therefore on geometry, size and orientation of the created elements. An exemplary model of syndesmosis on a scale of 4:1 made with ProJet CPX 3000 device is presented in figure 6.

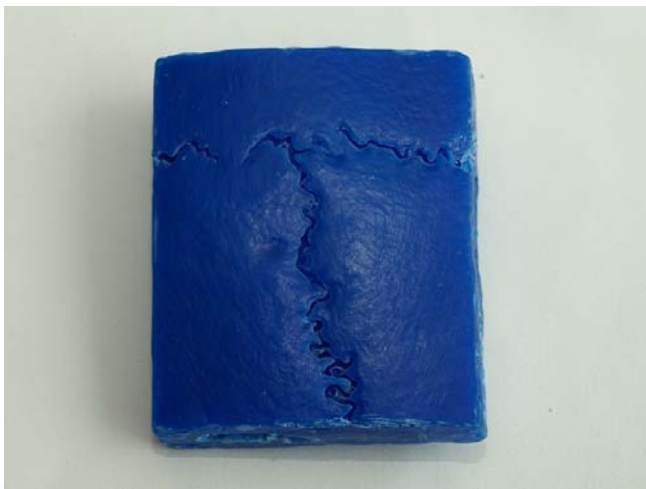


Fig. 6. A model of syndesmosis made with ProJet CPX 3000 device

3. Vacuum Casting RT method

The RP models fabrication is very expensive due to material costs and machine amortization. According to these facts, when destructable testing is needed, to obtain reliable results, it can be beneficial to prepare vacuum casted medical model sets fabricated with significantly cheaper materials i.e. Epidian 5. In this case, medical models fabricated with RP methods can be base for silicon block preparation for Vacuum Casting.

The Vacuum Casting method is one of RT (Rapid Tooling) techniques for fast fabrication of machine elements, prototypes and medical models. The method consists in making silicone moulds on the basis of models created in most cases with RP techniques. Experimental tests often imply damaging the model so direct use of prototypes made with RP methods becomes too expensive [6,7]. The silicone moulds are therefore made with the aim of casting medical models applying cheaper materials for example epoxy resins. A disadvantage of this method is impossibility of reconstruction the inside structures unlike in some RP techniques (except for the lost wax method). In case of photoelastic tests, the layout of stresses on the surface of the tested model is analysed with the reflected light method. That is why fabricating models with Vacuum Casting method is the only way to obtain a greater number of cheaper models which makes it possible to carry out numerous experimental tests.

3.1. Stages of process:

Fabricating the silicone moulds consists of the following stages:

- preparing a moulding box of appropriate capacity,
- preparing models of venting and pouring gates,
- making modelling sets by combining models of venting and pouring gates with a model created with RP techniques,
- placing the modelling set in the moulding box,
- preparing liquid silicone compound for making a mould,
- filling the moulding box together with the modelling set with the silicone compound,
- degassing the moulds in a vacuum chamber,
- heating the silicone moulds,
- separating the moulding box from the silicone mould block,
- generating of division surface of silicone moulds,
- the RP model removal.

The first step is analysing the shape and size of prototype model in order to fit an appropriately adjusted moulding box. The box size should ensure stable placing of the modelling set and diminish the capacity of the applied silicone.

An advantage of silicone moulds is their flexibility and thanks to it the process of separating them from a model is easy. In spite of it one should anticipate split lines of moulds analysing the model shape so that it was not destroyed and anticipate the arrangement of venting and pouring gates which together with the model constitute the so called modelling set. The channels can be designed at the stage of creating the STL model making them ready with RP techniques together with the model or one can make use of other arbitrary shaping methods directly on the ready prototype.

An exemplary moulding box together with fixed modelling sets is shown in figure 7.

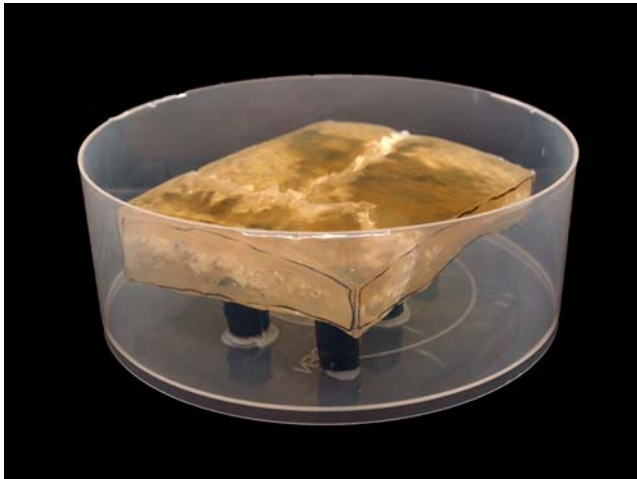


Fig. 7. A moulding box together with modelling set

The next stage is preparing the silicone compound. A set of liquid silicone together with hardening agent MM240 TV A+B mixed by a proportion of 1:10 was used for fabricating the moulds. After mixing the ingredients carefully the silicone should be initially degassed in Vacuum UHG 400, a device for vacuum casting in negative pressure vacuum of 2-50 hPa (fig.8).



Fig. 8. Vacuum UHG 400 device for vacuum casting

Then the moulding box should be filled with the silicone compound and degassed again. During the degassing process the capacity of the silicone compound rapidly increases because of frothing of the silicone. That is why it is necessary to take that

phenomenon into account while fitting the moulding box to prevent wasting the silicone compound.

After silicone hardening, the moulding box can be removed (fig. 9).

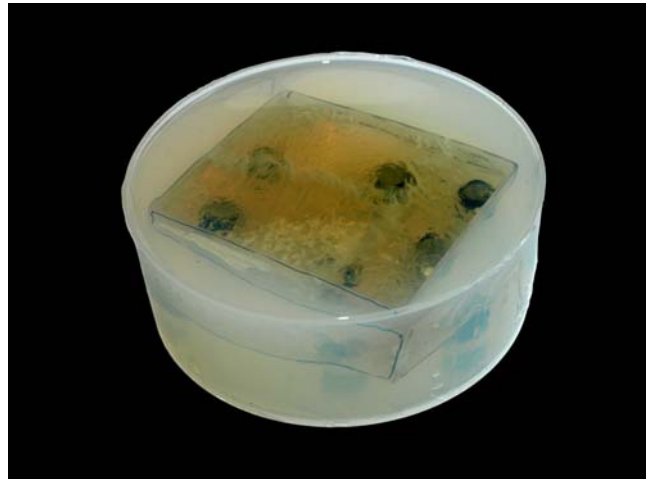


Fig. 9. The whole modelling set immersed in silicone mould block

After the silicone hardens it is necessary to divide the silicone mould along plains ensuring separating the mould's parts. An example of the mould's division into individual elements are presented in figure 10.

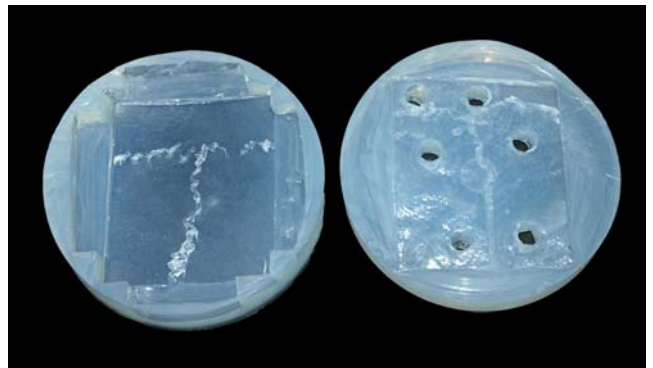


Fig. 10. Corresponding halves of silicone mould block

After taking out the modelling set and cleaning the separated parts of the moulds, they can be assembled again. Parting line should be conducted so that the mould's elements are perfectly adjusted to each other and cannot be displaced. To ensure stability the assembled mould can be placed again in the moulding box on condition that it has not been destroyed earlier. Boundaries where the individual elements are combined can be additionally sealed on the outside surfaces with quick-drying silicone. The mould prepared in this way should be subsequently filled with epoxy resin for example Epidian 5.

The moulds can be separated again only after full polymerization of the resin.

After taking the model out of the mould it is necessary to clean it precisely and remove the venting and pouring gates.

The medical model of syndesmosis has been founded with the use of such prepared silicone mould (fig.11).

The cast of medical model of cranium manufactured with this technology, as an example, is shown in figure 12. The casts have been fabricated with Epidian 5 epoxy resin.



Fig.11. The model of syndesmosis made of epoxy resin Epidian 5



Fig.12. Model made of Epidian 5 resin ready for photoelastic experiment

The sets of medical models will be used for strain and stress analysis with photoelastic method with extreme load conditions.

The additional advantage of silicone moulds is their high durability, which allows for using them many times to fabricate a greater number of models.

4. Conclusions

Rapid Prototyping and Rapid Tooling methods together with computer aided systems CAD/CAM make it possible to carry out numerical analysis and experimental tests on models of very complicated inside and outside shapes. RP techniques allow for fabricating medical models with of tissue structures with complex spatial geometry. It has a significant influence on the obtained final results, which are very close to the real ones. RT techniques and precisely Vacuum Casting method allows for making models of cheaper epoxy resins and for using the casting forms many times. There is a possibility of analyzing much bigger range of cases of loading regardless of the costs connected with fabricating medical models. Therefore applying Rapid Prototyping techniques for fabricating medical models allows for achieving new quality in experimental tests.

Acknowledgements

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Metody wytwarzania modeli medycznych o złożonej strukturze przestrzennej

Streszczenie

W artykule przedstawiono proces tworzenia modeli medycznych przeznaczonych do badań eksperymentalnych z wykorzystaniem nowoczesnych metod szybkiego prototypowania. Scharakteryzowano wybrane metody Rapid Prototyping począwszy od JS – PolyJet, SLS, ProJet, a skończywszy na metodzie odlewania próżniowego Vacuum Casting. Omówiono możliwości ich wykorzystania w badaniach modelowych, a w szczególności w badaniach elastooptycznych, na przykładzie górnej części czaszki i fragmentu więzozrostu czaszkowego. Metody szybkiego prototypowania RP i RT z jednoczesnym wykorzystaniem komputerowych systemów wspomagania CAD/CAM pozwalają na przeprowadzenie analizy numerycznej jak i badań eksperymentalnych na modelach o bardzo skomplikowanych kształtach wewnętrznych jak i zewnętrznych. Techniki RP umożliwiają wykonanie modeli medycznych z dokładnym odwzorowaniem kształtu analizowanych elementów szkieletu kostnego. W przypadku badań elastooptycznych, gdzie konieczne jest uszkodzenie badanych modeli medycznych, techniki RT oraz techniki VC, umożliwiają szybkie ich wykonanie w rozsądnych cenach i w ilości wystarczającej do badań. Dzięki temu istnieje możliwość przeanalizowania znacznie rozszerzonego zakresu przypadków obciążania przy ograniczeniu kosztów badań. Zastosowanie technik szybkiego prototypowania do wykonywania modeli medycznych rozszerza możliwości badań eksperymentalnych w medycynie.