Publishing House
AKAPIT

COMPUTER METHODS IN MATERIALS SCIENCE
Informatyka w Technologii Materiałów

Vol. 11, 2011, No. 2

COMPUTATIONAL METHODS IN THE SLA AND FDM TECHNIQUES IN THE PROCESS OF PRODUCTION OF AN AIRCRAFT WHEEL HUB PROTOTYPE

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Abstract

The rapid prototyping process was carried out on the example of an aircraft wheel hub and the key role of information operations performed at each stage was stressed. The design and its verification in a CAD system environment was completed. Parts were assembled and tested on their mutual cooperation. Basing on the model of 3D CAD a model of finite elements method was constructed and the tension distribution analysis was made. Tasks performed, supported by the CAD algorithms, made it possible to generate a final version of the solid model. On its basis, an STL model constituting a base for the process of RP was developed and verified. Using software tools RP processes SLA and FDM were developed. The simulation of overlapping layers was carried in order to eliminate errors in the relevant physical processes. The numerical routines were generated for the apparatus: SLA 250/50 and uPrint. Prototypes of hub were made on the basis of stereolithography techniques and liquid plastic modeling. The coordinate measurements of models were carried out and errors specific to each method were analyzed.

Key words: aircraft wheel hub, rapid prototyping, CAD, SLA, FDM, STL

1. INTRODUCTION

Rapid prototyping systems require a series of computer operations at the stage of developing technology and manufacturing a prototype.

Figure 1 presents an algorithm for computing procedures performed during the RP.

RP techniques allow you to make prototypes of very complex shapes, advanced designs, which include aircraft parts (including the developed and tested hub). The application of rapid prototyping systems is particularly important for the manufacture of those aircraft parts for which it is difficult or impossible to use traditional methods and tools (Chlebus et al., 2005; Chlebus, 2000; Horvath & Yang, 2002; Gebhardt, 2003).

Manufacturing prototypes with RP methods is related to the computer data preparation, process control and verification of models. The particular stages are implemented by CAD systems, RP utilities and the software for analyzing the results from the measuring devices (Stroud & Xirouchakis, 2000; Bubicz, 2008; Haraburda, 2005; Ambroziak, 2005)..

The first part of the algorithm presents operations of computing performed in the CAD environment Designing a model is carried out based on the CAD algorithms. The next step is an export to STL format and a subsequent analysis of the surface after tessellation (preview of generated triangle mesh describing the model) (Lee et al., 2002; Nee et al., 2001).

 ISSN 1641-8581

The presented program of research and measurement is associated with the processes of laser sterolithography - SLA and the fused deposition modeling - FDM. The techniques use the process of constructing the model by material gain, involving its gradual addition, until the desired shape (Bernard, 2000; Bullinger et al., 2002; Budzik & Markowski, 2009; Liu, 2008).

The second part of the algorithm presents operations of computing performed by the RP software tools. The essence of the operation is to convert geometry of the model, which is divided into layers implemented in the elementary steps of operation of the apparatus. The process of preparing data in a dedicated utility for the particular RP method is a key step for the correct implementation of the prototype such as the aircraft wheel hub. The correct models position on the working platforms, editing of auto-generated supports and the verification of the output files (an analysis of the simulation of application layers) allows minimizing the risk of damage of the prototypes during the manufacturing process as well as in the subsequent finishing technology and subsequent processing can be determined.

2. DEVELOPMENT OF CAD DESIGN

Creating models of the aircraft parts requires the use of sophisticated CAD systems with hybrid modeling capabilities (solid and surface) (CATIA, NX - Unigraphics, Autodesk Inventor, SolidWorks). Complex shapes can be made using surface modeling options. The generation of physical prototypes and the export of data into a format of RP equipment requires the transformation of a surface or edge model into the CAD solid model.

A very important step in preparing the numerical data for RP processes is an insightful analysis of the CAD documentation (figures 2ab).

Integrated engineering systems allow developing FEM (Finite Elements Method) models (figure 2c) on the basis of 3D CAD models and the analysis of tension distribution (figure 2d), which allows an initial verification of the structure. FEM results will be reviewed in comparison with elastooptic analysis which will allow an adjustment in the computerized procedure of FEM (if they differ from the physical experiences). Discrepancies in FEM research usually result from incorrectly defined assumptions (distribution and number of nodes, the type of elements, boundary conditions, the parameters of the forces, material properties) (Kopecki, 1992; Kopecki & Witek, 2000; Rakowski & Kacprzyk, 2005).

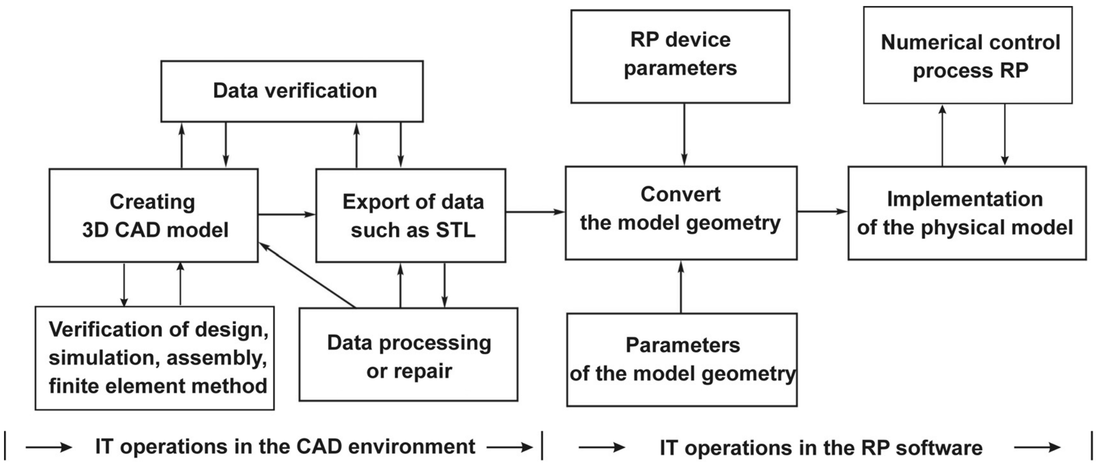


Fig. 1. IT operations in the process of rapid prototyping.

The processes of rapid prototyping supported by several software tools let to select and define the standards for application the computational methods to create models of elements of structure.

Specific requirements for aircraft structures to use RP techniques make it necessary to identify special numerical service procedures which are the subject of this paper.

Thanks to the physical models obtained in the processes, the hub construction can be verified on the basis of applying the target material, a magnesium alloy for aircraft parts, and its development

The final stage of work in a CAD system environment is generating a file in STL format (Standard Triangulation Language) on which utilities of SLA and FDM methods are based.

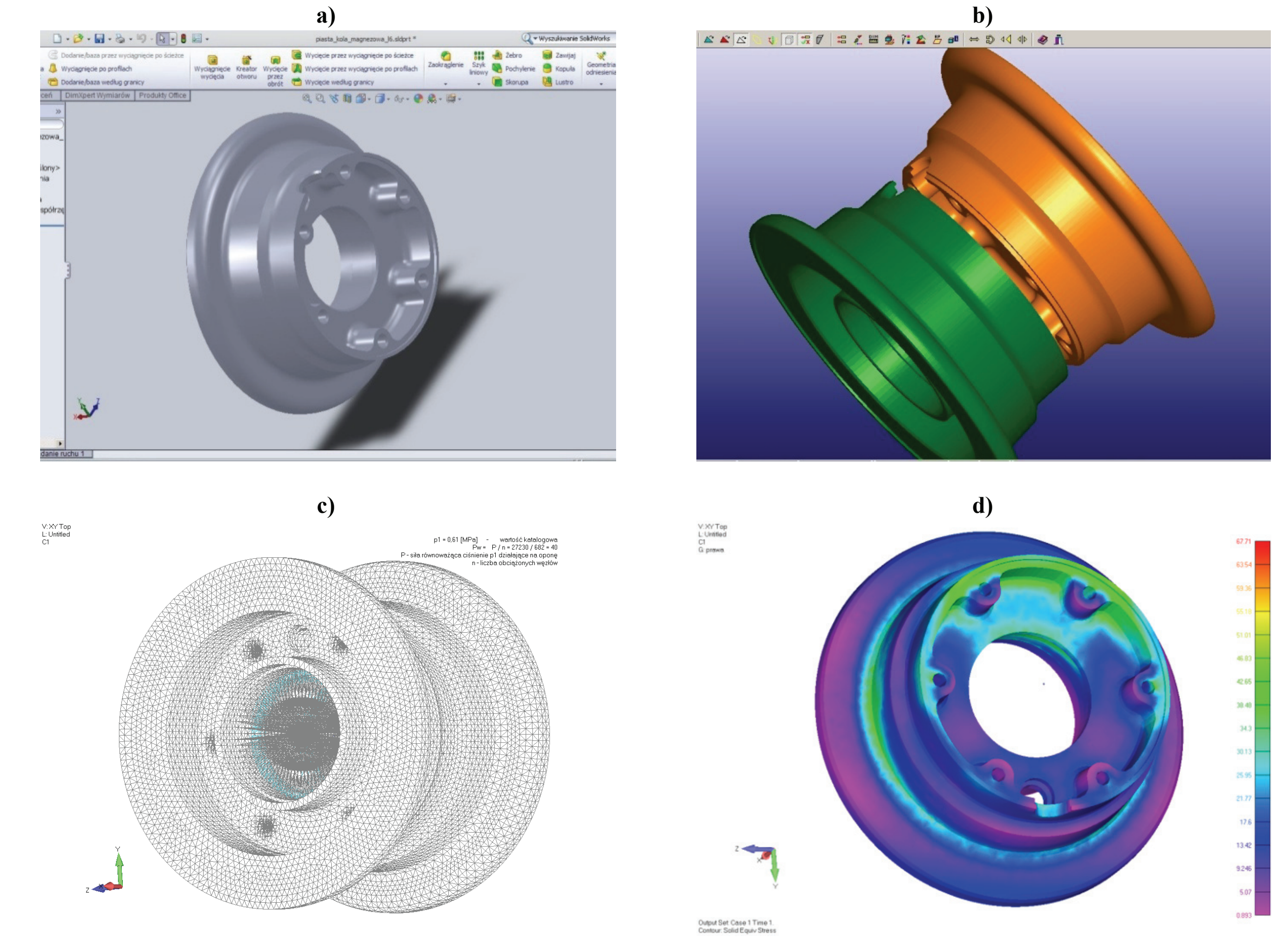


Fig. 2. Development of an aircraft wheel hub design in the CAD system: a) 3D CAD solid model, b) the complete hub – submission review, c) FEM model, d) analysis of tension distribution.

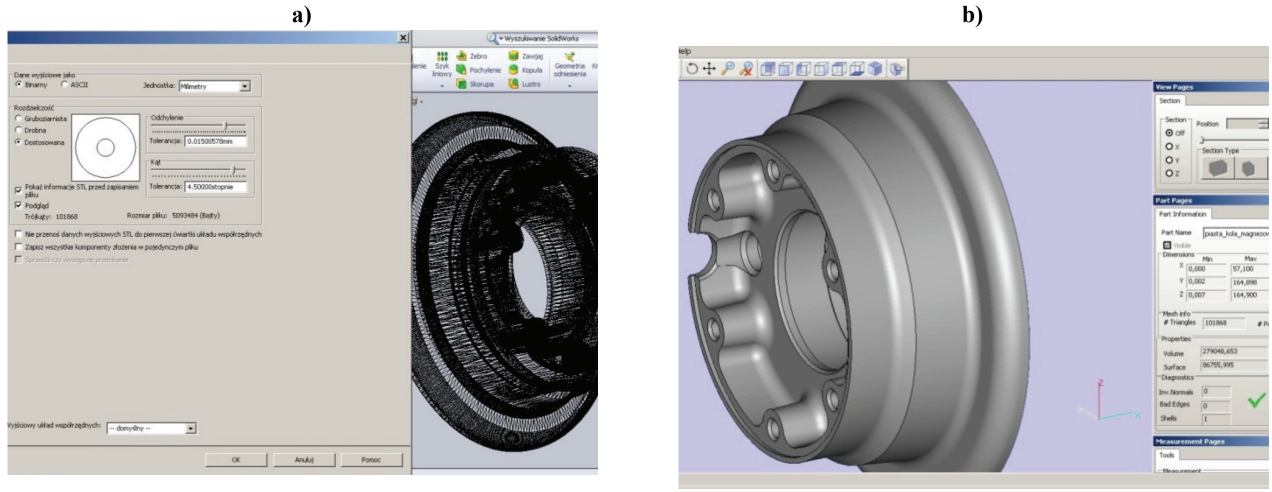


Fig. 3. STL model: a) Generating, b) Review.

Tessellation - generating STL files – is a process in which three-dimensional model geometry is approximated by triangular surfaces. The size and shape of the triangles can be adjusted by setting the relevant parameters to data export (figure 3a). The accuracy of approximation depends on the shape of the model surface and the given values of tolerance and angular deviation.

Bad selection of listed parameters results in inaccurate representation of the surface of the model in the later RP process.

Therefore, the next very important step in preparing data for RP is the analysis of generated STL models (figure 3b).

There are frequently errors in STL files, which make it impossible to carry out the subsequent processes of RP. This results from an error in batch CAD design or software algorithms applied during the export (each structure is a separate task forcing individual mathematical relations on the CAD / STL module). Some browsers of STL files allow editing and correcting basic errors. For the most part, however, the STL format must be re-generated, and the correctness of the CAD model must be previously checked.

3. DEVELOPMENT OF RP PROCESSES

Correctly generated STL file allows the preparation of the process (development of the procedures for implementing the apparatus of the SLA and FDM) on the basis of the utilities.

3.1. Stereolithography - SLA

The first stage of work in 3DLightyear is processing data such as the type of resin used (SL5170), determining the thickness of the polymerized layer (0.1 mm), selecting the styles of models and supports, the scraper work, the times of the process (dipping, sliding the scraper, the spacing time for each layer). Those parameters are determined for the individual requirements of each process - depending on the type of generated models.

The next step is importing the STL model of an airplane wheel hub to the previously prepared window of a work platform. It is necessary to set the model appropriately, i. e. to choose the most advantageous surface of support (from the viewpoint of construction and purpose), the risk of damage during the subsequent separation from the platform and removal of the supporting structure must also be taken into account.

The set model should be revised in the direction of the correctness of the STL format. Very often, minor errors in describing the surface are omitted from the preliminary analysis and may result in damage to the model during the process. The 3DLightyear program verifies a model and corrects basic errors (of single triangles) by replacing the model on the platform - a new file name is added to the source folder * _v.stl.

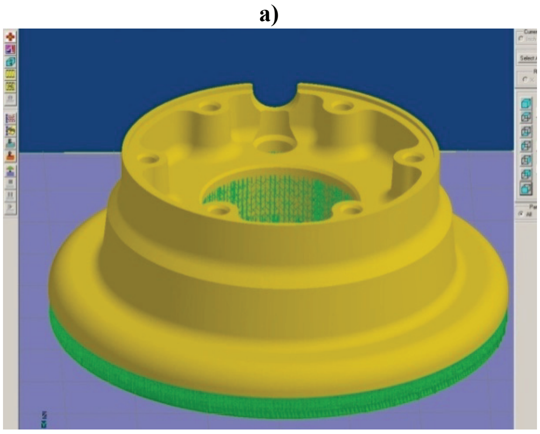
A successfully verified SLA model needs to be "supported" (figure 4a) with the use of the automatic generation algorithms offered by the software (according to pre-defined styles).

After generating the supporting structure it should be analyzed and edited if necessary.

After editing supports the data are prepared for the apparatus SLA250/50 – the 3DLightyear program divides the model and its support structure on layers storing information about each of them in four files.

After completing data conversion, output files are saved in a program subfolder 'Build', the most important file with the extension "*. v" - so called vector file - contains information about the polymerization of the individual layers. That file should be opened in a new window of the 3DLightyear program for the analysis of the process (figure 4b).

a)



b)

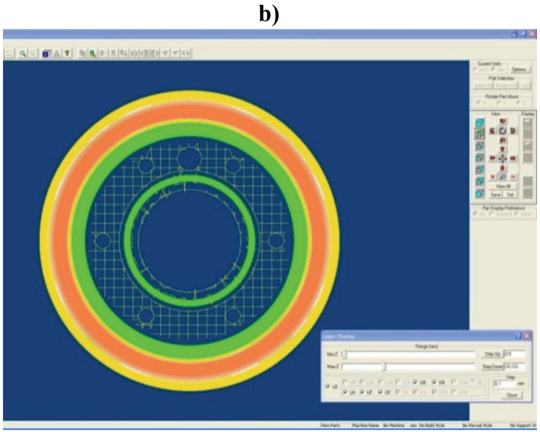


Fig. 4. Preparation of the SLA process: a) model with a supporting structure, b) verification of the individual layers.

Analysing the individual layers one should pay attention to their continuity, shape and position in relation to each other. In case of errors or omission of layers, the platform should be recalibrated (the files to the machine).

3.2. Fused deposition modeling - FDM

Another rapid prototyping method for the wheel hub is modeling with the liquid plastic - FDM.

As in the case of stereolithography, a key step to a properly conducted FDM trial is an appropriate STL model analysis and generating numerical data for the uPrint machine in a QuickSlice software.

After importing the hub model on the work platform it should be properly set in relation to a frame of reference.

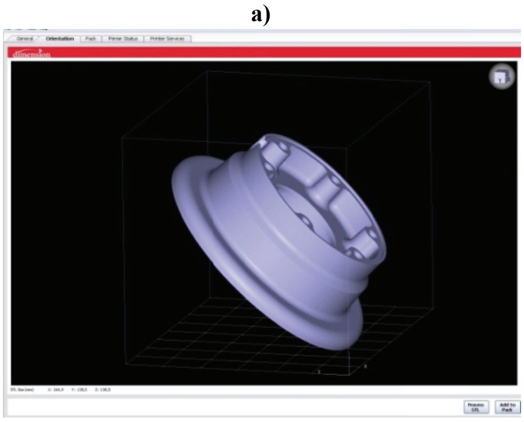
Unfortunately the dimensions of the model go beyond the cubic limitations of the machine, which forces a different way of setting the hub – 45-degree gradient in relation to the XY plane is necessary (figure 5a).

After making sure that the position of the model is optimal and feasible in the planned process, one can proceed to generate the supporting structure.

Before exporting the data to the apparatus, all layers are analyzed (figure 5b). There is a risk of incorrectly converted layers, which can cause damage to the prototype. In case of errors, remodelling is necessary.

A successfully developed process can be started – exporting the data to the machine follows.

a)



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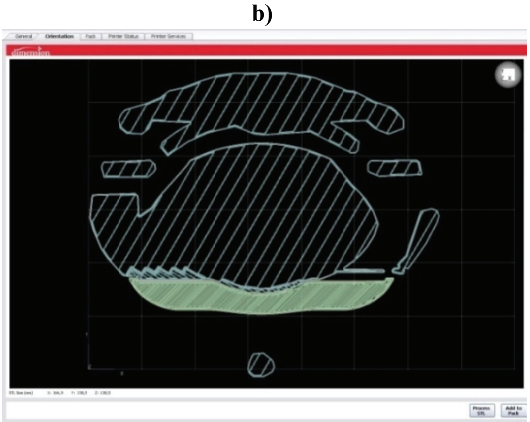


Fig. 5. *Preparation of the FDM process: a) setting a model, b) verification of the individual layers.*

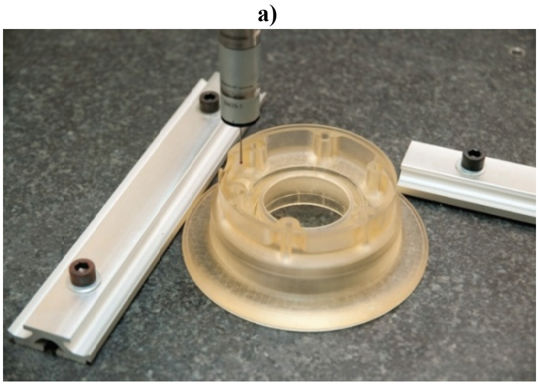
5. MODELS MEASUREMENT INSPECTION

The SLA and FDM prototypes of a wheel hub were measured by the WENZEL machine.

The starting point for measurements was the export of a hub solid model to the IGES format which forms the basis of reference for the software controlling the measuring machine.

Subsequently, the prototypes were placed on a workbench (figure 6) and a series of points measurements was conducted on characteristic surfaces.

a)



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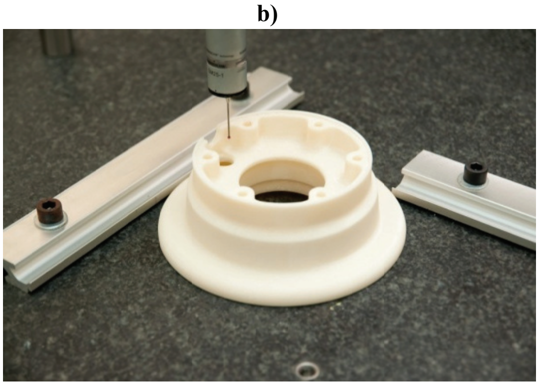


c)

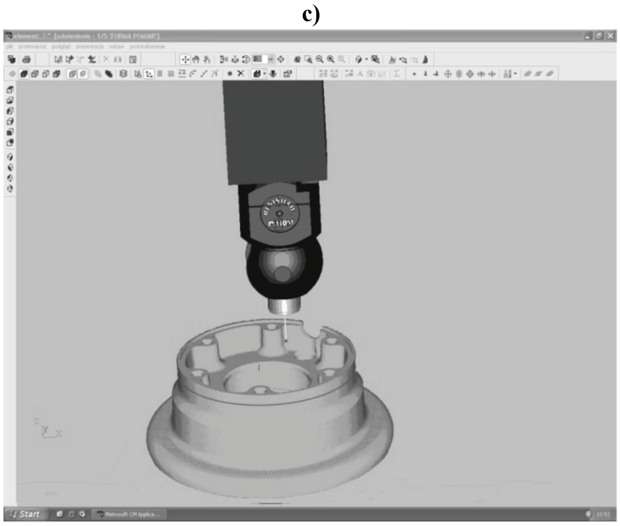


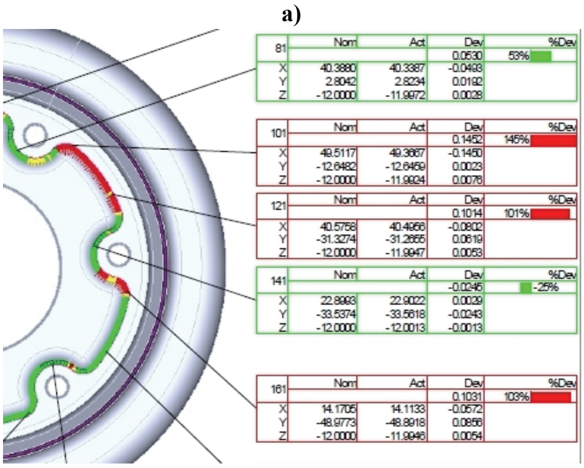
Fig. 6. *Coordinate Measurement of aircraft wheel hubs prototypes: a) SLA, b) FDM, c) measuring machine software toolbox.*

The analysis of test reports (figure 7) leads to the conclusion in the case of negative errors for the FDM prototype and positive for the SLA.

The absolute size of recorded corrections indicates the clear advantage of FDM technology. However, one should remember that we deal with the shrinkage which is difficult to overcome in the finishing, and filling the model will be necessary.

On the other hand, the positive patch of the SLA prototype is the result of the supporting structure and side 'steps' of subsequent layers which are easy to remove during final grinding and polishing.

a)



b)

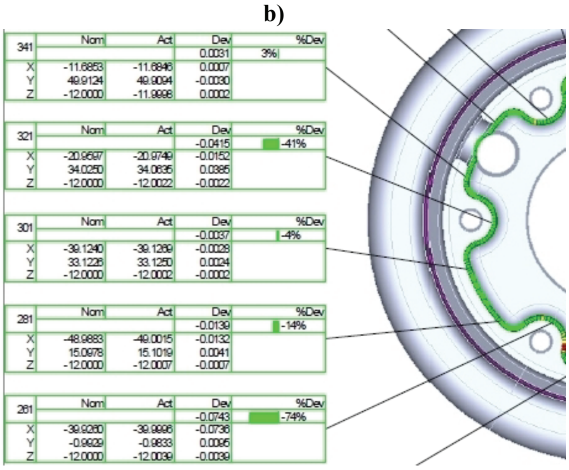


Fig. 7. *Models measuring reports: a) SLA, b) FDM.*

6. SUMMARY

The examination of the results allows the following conclusions:

1. CAD design and verification is both first and the most important phase in the so-called product life cycle. The proper software selection (algorithms, based on which calculations are made) allows for the development of comprehensive data for the RP process.
2. Special attention was paid to the need for proper export of 3D CAD to STL and the subsequent form of verification.
3. The process of preparing data in dedicated utilities (a key step for the proper implementation of the prototype) was shown.
4. The correct position of the models on the working platforms, auto-generated supports editing and output files verification (an analysis of the simulation of layers application) allow minimizing the risk of prototypes damage during the prototyping process itself as well as the subsequent finishing.
5. Measurements of the prototypes and the computer interpretation of the results helped to determine the suitability of the RP methods used in the implementation of industrial elements of aircraft structures.
6. Models produced in the process of RP are burdened with an error:
   – SLA shows more correction - but it is an easily correctable error during the so-called 'post processing'.
   – FDM is of a higher accuracy but errors are contraction – one should therefore consider the possibility of compensation for this method at the stage of CAD modeling.

ACKNOWLEDGMENTS

Financial support of Structural Funds in the Operational Programme - Innovative Economy (IE OP) financed from the European Regional Development Fund – Project 'Modern Material Technologies in Aerospace Industry', Nr POIG.01.01.02-00-015/08-00 is gratefully acknowledged.

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METODY OBLICZENIOWE W TECHNIKACH SLA I FDM W PROCESIE WYTWORZENIA PROTOTYPU PIASTY KOŁA SAMOLOTU

Streszczenie

Przeprowadzono proces szybkiego prototypowania na przykładzie piasty koła samolotu podkreślając kluczową rolę operacji informatycznych wykonywanych na każdym jego etapie.

Zrealizowano konstrukcję oraz jej weryfikację w środowisku systemu CAD. Dokonano złożenia części oraz sprawdzono ich wzajemną współpracę. W oparciu o model 3D CAD zbudowano model do analizy metodą elementów skończonych oraz przeprowadzono analizę rozkładu naprężeń. Wykonane zadania, wspierane przez algorytmy CAD, pozwoliły na wygenerowanie finalnej wersji modelu bryłowego. Na jego podstawie opracowano i zweryfikowano model STL stanowiący bazę dla procesu RP.

Korzystając z narzędzi programowych RP opracowano procesy SLA oraz FDM. Przeprowadzono symulację nakładania kolejnych warstw celem wyeliminowania błędów we właściwym procesie fizycznym. Wygenerowano procedury obsługi numerycznej dla aparatury SLA 250/50 oraz uPrint.

Wykonano prototypy piasty technikami stereolitografii oraz modelowania ciekłym tworzywem.

Przeprowadzono pomiary współrzędnościowe modeli analizując błędy charakterystyczne dla każdej z metod.

Procesy szybkiego prototypowania wspierane przez szereg narzędzi programowych pozwoliły wyselekcjonować i określić standardy zastosowania metod obliczeniowych do wykonywania modeli elementów konstrukcji.

Zaostrzone wymogi w odniesieniu do konstrukcji lotniczych wykonywanych technikami RP wymuszają konieczność określenia szczególnych procedur obsługi numerycznej co stanowi przedmiot niniejszej pracy.

Received: December 12, 2010
Received in a revised form: December 23, 2010
Accepted: December 23, 2010