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The use of Rapid Prototyping technique in PhotoStress® method

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BIOGRAPHICAL NOTES

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Ing. Mária Kenderová after successful completion of her study at the SPŠS in Kosice she has started studies at the Faculty of Mechanical Engineering of the Technical university of Kosice. She graduated a bachelor-degree study in General Engineering in 2008. Thereafter she continued an engineer-degree study in Automotive Production. She defended his diploma thesis „Inovative methods of product design - design of automotive component." in 2010. Nowadays she is a student of PhD-degree study in Applied mechanics.

KEY WORDS

Prototype, Rapid Prototyping, Rapid Tooling, PhotoStress® method

ABSTRACT

The subject of this paper is Rapid Prototyping method which is a widely expanding technique for quick and modern production of prototypes, models and tools by means of non-conventional technological procedures. The paper further presents the ways in which the technique can be used in PhotoStress® method. In the effort to speed up the whole process of product development it is crucial to select appropriate production technology. With conventional methods applied, the production of models is often expensive and, in a number of cases, ineffective. Therefore, new technologies such as Rapid Prototyping are coming into focus. These high-quality technologies are faster and can be widely used in a variety of fields. Rapid Prototyping (RP) covers a group of technologies used in the production of component models or assembly groups while using 3D CAD (computer aided design) data.

1. Introduction

Rapid Prototyping (RP) as a method of quick production of prototypes, together with Rapid Tooling (RT) being a method of quick production of tools, can significantly cut time and costs in the production of prototypes. RP and RT enable us to reach higher qualitative parameters and shorter development phases of a new product and, in this way, shorten the cycles of innovation and by and large strengthen competitiveness of a company.

The subject of this paper is the use of quick prototyping in the automotive industry. Attention is paid mainly to the method and technique of Rapid Prototyping and Rapid Tooling, their technological as well as application aspects in automotive manufacturing and trends in research and development.

Currently, the production of goods is to meet the requirements for development speed up and quick introduction of new products to the market.

Software application PhotoStress shall speed up the determination of particular principal strains and principal normal stresses as performed by means of PhotoStress® method. The aim of the application is to determine directions and magnitudes of principal strains and principal normal stresses on photoelastically coated prototypes which were made by Rapid Prototyping technique, components or constructions while using the principles of reflection photoelasticity or PhotoStress® method.

2. The use of Photostress® Method

PhotoStress® method is a frequently used technique for precise measurements of surface deformations and for determination of stresses in a model, component or a system during static or dynamic loading [9].

In PhotoStress® method a special strain-optic sensitive coating is bonded to tested component. When optically sensitive photoelastic coating on a component is illuminated by polarized light from reflection polariscope and when viewed through the analyzer of the polariscope, deformations of stresses will be seen as colourful isochromatic fringes. Isochromatic fringes provide us with information about distribution of strains or stresses on the whole surface under analysis and about maximum strain values in deformation areas. Compensator attached to the reflection polariscope enables us to carry out a quick quantitative stress analysis. Furthermore, it is possible to make photographic or video records in order to gain information on stress distributions.

Reflection photoelasticity or PhotoStress® method enables us to [7]:

- *identify critical areas,*
- *highlight low- and high-stress areas,*
- *measure stress peaks and determine stress concentrations around holes, notches, curvatures and other possible failure areas,*
- *measure principal normal stresses and their directions in various points of photoelastic coating,*
- *repeatedly carry out measurements at various loads without new photoelastic coating to be applied,*
- *perform laboratory or outdoor measurements,*
- *identify and measure residual stresses,*
- *determine elastic deformations and record redistribution of deformations in plastic area.*

3. The Principle of Rapid Prototyping Method

Rapid Prototyping (RP) refers to technologies used for quick fabrication of a model, sample or prototype using three-dimensional computer aided design (CAD) or three-dimensional scanned data gained by 3D digital imaging. In comparison to conventional methods, the production of a prototype by means of Rapid Prototyping is considerably shorter.

Rapid Prototyping provides, on the one hand, quick production of models, samples and prototypes in any phase of development and, on the other hand, enables us to fabricate a complex series of modifications and structural compositions of a proposed product without using moulds and tools.

In contrary to conventional technologies, where layers of material need to be removed, with Rapid Prototyping the shape of a model is made by gradual addition of layers of paper, plastic or metal sheets, powder, thermoplastic mass or photopolymer (light-sensitive plastic mass which is gradually hardened by laser or ultraviolet light) until the final shape of prototype is reached. In this way we can fabricate any shape of a hollow component or a component with oblique as well as horizontal lower walls in a considerably short time. In these cases the conventional methods are limited in their use.

RP technology is based on computer aided interpretation of a three-dimensional object in a CAD system. This interpretation provides direct entrance into technological device which forms physical object that exhibits properties similar to the final product even without complex preparation phases and specialised tools. Fig. 1 depicts basic scheme of Rapid Prototyping method [1].

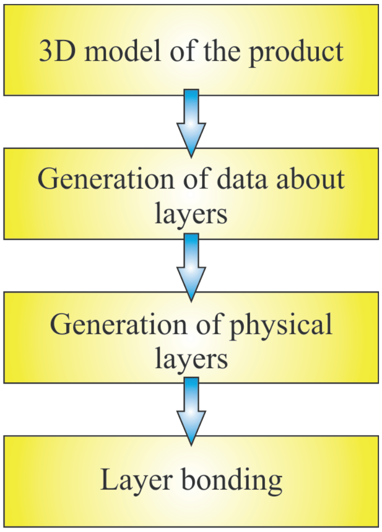

Fig. 1: *The principle of Rapid Prototyping method [1].*

Rapid Prototyping includes following technologies:

- *Stereolithography (STL),*
- *Selective Laser Sintering (SLS),*
- *Laminated Object Manufacturing (LOM),*
- *Solid Ground Curing (SGC),*
- *Fused Deposition Modelling (FDM),*
- *Multi-Jet Modelling (MJM).*

The choice of a particular RP technology is made by every single laboratory or workplace and is dependent upon the object subject to examination. Models fabricated by means of Stereolithography (STL) can undergo stress analysis carried out by transmission fotoelasticity. Fused Deposition Modelling (FDM) and Selective Laser Sintering (SLS) are appropriate for the combination of Rapid Prototyping and PhotoStress® method.

Stereolithography (STL)

With STL the component is layer-fabricated while liquid photopolymer is hardened using UV laser (photopolymerization). On the basis of advance data about shapes and sizes of cross cuts of particular planes (layers) are calculated controlling data which lead the laser ray by means of XY scanning head placed above upper part of the vessel filled with liquid polymer. The component is being made on supporting plate which was placed directly below the level of polymer at the beginning of the process. Three-dimensional body (model) is made by modelling separate layers of liquid polymer. The model is then removed from the supporting plate. Such body represents a number of technical products in case of which a quick and repeated production of models and samples is required. The body may later be used as a tool for verification of construction accuracy, ergonomic features, design, and to prove whether the construction can at all be fabricated and assembled. It is found helpful when communicating with the supplier and customer or when providing them with arguments. The process of component production would take weeks while using conventional methods.

Stereolithography cuts the production time to a few hours. Such considerable cut of production time is a great advantage as regards development costs as well as time until the new product appears on the market. The scheme of the modelling process using STL technology is depicted in Fig. 2.

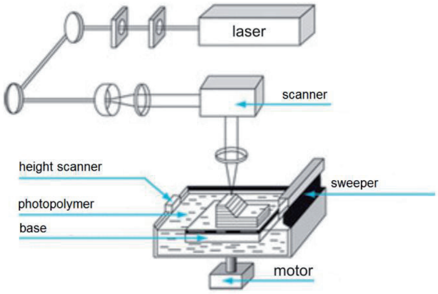

Fig. 2: *Modelling process using the technology of Stereolithography (STL) [8].*

Fused Deposition Modelling (FDM)

In FDM process the component is fabricated through gradual addition of layers of material which is being released from heated nozzle moving in x - y direction above the space in question. The material in the shape of a wire is being led to the nozzle where it is heated up until it reaches temperature which is 1°C higher than the melting point of a wire. The material solidifies when reaching the surface of fabricated component and makes up the required layer. The component is fabricated on the supporting plate. After the layer was applied, the plate is lowered by the thickness of applied layer. The application of another layer starts next. Additional supporting frame (this can be made of bitumen sheet) is needed to support outstanding parts of the model. In this way we can make components from polyamide, wax or polyethylene. The scheme of the modelling process using FDM technology is depicted in Fig. 3.

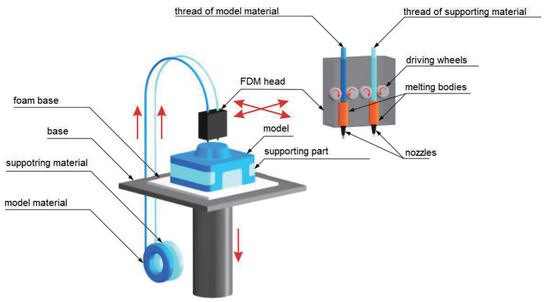

Fig. 3: *Modelling process using FDM technology [8].*

The use of Rapid Prototyping technologies is advantageous mostly with respect to time cut in fabricating physical models (prototypes). Models can be used, apart from verification of shape and functionality and design revision, in strain and stress analysis as carried out by means of experimental methods.

3. The use of RP Models In Photostress® Method

Design engineers and technologists in the field of engineering may find Rapid Prototyping technologies even more attractive since these high-quality technologies are fast and can be applied in a variety of fields. The design of various engineering components in vehicles, structural parts, components etc. can be found among these fields. An overview of engineering fields in which Rapid Prototyping may be used can be found in Table 1. Fig. 4 depicts a round disk which was made using Rapid Prototyping method. The disk was coated with photoelastic coating PS-1.

Fig. 4: *Isochromatic fringes on the round disk with photoelastic coating PS-1 being applied to the disk.*

Models fabricated by Rapid Prototyping method may contain pores or elastic bumps what is likely to directly affect structural response.
In contrary to other experimental techniques, PhotoStress® method enables us to observe stress distribution along whole surface under analysis.

Fig. 5 and Fig. 6 depict models which were made using Rapid Prototyping method. These models can undergo strain and stress analysis by means of PhotoStress® method while using photoelastic plane plates or contourable photoelastic sheets [1].

Table 1: *Overview of Rapid Prototyping technologies and their use*

Technology Abbreviation	Materials	Manufactured prototypes (tools used in the production) of car components, application
Stereolithography STL	Liquid acrylate, epoxide and urethane photopolymere resins	Dashboard, handbrake, lights, mirror, wing, emblem, radiator shroud, hubcap, fuel system, bumper, F-head, steering wheel, air filter, cast parts of an engine, child safety seat, model of a car body, airbag cover and ring, interior components etc. The material is applicable for design assessment, production of casting moulds, with some limitations for functionality tests and as casting mock-ups in the method of reducible model.
Automated laminating LOM	Paper, plastic sheets	Axle arm, wheel suspension, car body, dashboard etc. These are generally low-detail parts. Can be used mainly for design assessment, limited as regards mould fabrication.
Thread application FDM	Waxes, ABS	Cover of air-conditioning, wheel suspension. Applicable for design assessment, production of casting moulds and casting mock-ups in the method of reducible model, with some limitations for functionality and assembly tests.

3D Printing InkJet BPM	Waxes	Small-size components, parts of an airbag, interior components etc. Material is applicable for design assessment, production of casting moulds, with some limitations for functionality and assembly tests. Especially appropriate for casting mock-ups as made by the method of reducible model.
Selective Laser Sintering SLS	Plastic, metal and composite powders	Dashboard, handbrake, lights, mirror, wing, emblem, radiator shroud, hubcap, fuel system, bumper, F-head, steering wheel, air filter, parts of an engine, child safety seat, model of a car body, seat, interior components etc. Functioning prototypes of a fan, centre console, flexible cable channels, fuel system. Material is applicable for design assessment, production of casting moulds, with some limitations for assembly and functionality tests. It is possible to fabricate fully functioning prototypes and small series of series-quality products.

Wheel disk SMART
(DSPC)

Hubcap model
(STL)

Prototype of a front seat in a car (SLS)

Steering wheel
(SLS)

Fig. 5: *Example models which were fabricated using Rapid Prototyping method [1].*

Fuel tank, fully functioning prototype
(SLS)

Centre console of a car
(SLS)

Rear bumper – Fabia WRC
(SLS)

Front wing – Fabia WRC
(SLS)

Fig. 6: *Example models which were fabricated using Rapid Prototyping method [1].*

4. Conclusion

It seems that computer aided fabrication of physical models is the most effective solution in the process of product development. Therefore, new technologies of Rapid Prototyping gain more attention as they enable quick production of physical models based on CAD system made 3D models.

Rapid Prototyping technologies represent a way in which we can transform data into a physical object. In addition to the quality and the price of a product, company management must consider time which is one of the most important factors. Time plays most significant role in product's competitivness on the market. Rapid Prototyping technologies enable stress analysis to be performed on a particular model and, hence, there is still some possibility of product optimization. Other possible fields for the use of Rapid Prototyping in PhotoStress® method will be published in future papers.

5. Acknowledge

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