Acta Mechanica Slovaca 16 (3): 68 - 73, 2012

* Corresponding author
*E-mail address: msobolak@prz.edu.pl*
(Mariusz Sobolak)

Article information
*Article history: AMS-Volume16-No.3-00156-12*
Received 4 January 2012
Accepted 15 March 2012

# Rapid Prototyping Techniques for Prototyping and Research of Polymer Gear Transmissions

**Mariusz Sobolak[1], Patrycja Ewa Jagiełowicz[2]**

[1] *Rzeszow University of Technology, Department of Machine Design, Al. Powstańców Warszawy 8, 35-959 Rzeszów, Poland*
[2] *Rzeszow University of Technology, Department of Machine Design, Al. Powstańców Warszawy 8, 35-959 Rzeszów, Poland*

## KEY WORDS
Polymer gears, Rapid Prototyping

## ABSTRACT
The article presents different fields of usage of Rapid Prototyping techniques in production and research of functional prototypes of polymer gears for electromechanical industry. Such Rapid Prototyping techniques as stereolithography and vacuum casting are used for preparing of functional prototypes of gears. The method of receiving of accurate gears made of differ plastics is shown. The gears are made by duplication of the stereolithographic model in the silicon matrices. The properties of stereolithographic resin are used in order to photo-elastic research – the determination of distribution of stresses in the gears of loaded transmission. The deformations of teeth of loaded transmission are frozen using vacuum casting. Beside the deformations, the tooth contact on the flank surfaces of teeth is obtained. The tooth contact can be also directly observed when the test gears are made of transparent plastic. The usefulness of Rapid Prototyping for production of accuracy gears and the usefulness of vacuum casting for freezing deformation and observation of tooth contact is shown in the conducted research. The presented solutions can be applied to the plastic gears. The presented possibilities of production and research of polymer gears can find a wide application in the electromechanical industry, that produced gears for drives of different types of devices, for example in the household equipments, in the motorization. The novelty is the usage of vacuum casting for freezing deformations of teeth in the static load transmission. The method allows preliminary verification of correctness of construction of gears basis of the received tooth contact – its size and location on the tooth flank.

## 1. Introduction
In recent years transmissions made of high quality plastics, are of greater importance than earlier in production of machines and devices. Also the tendency to use Rapid Prototyping techniques for prototyping of gears, is recently noticeable along with establishment and development of these techniques. The polymer transmissions meet requirements for the most of gears used in machines of electromechanical industry, also ecological requirements. The advantages of plastics, such as high abrasion resistance, high mechanical and chemical resistance, high utilize temperature, long life and corrosion resistance, maintenance-free or silent-running, make the plastic gears fulfill the right conditions to effective replace the metal gears. The low efficiency of trans-

mission with plastic gears is still a problem, so this kind of gears does not find applications in drives utilized continues and in power transmissions, but only in the devices that work sporadically (e.g. drives of car wipers, drives of car screens, drives of household equipments) [6], [13].

The newer constructional solutions of polymer gears appear as a result of slowly breaking down the stereotypes according to such gears were designed similarity to metal gears, but metal gears have been produced using classic method of machining. Using injection moulds is enable to carry out more complicated shapes than using classic methods of gear machining. The forming of injection mould is expensive, so Rapid Prototyping techniques are more often used in production of prototypes in order to build prototypes for preliminary tests [1], [2], [3], [4], [9]. In the paper was shown the exemplary using Rapid Prototyping techniques for prototyping and research of prototype of transmission. The novelty is indirect using these techniques for research of gears.

## 2. Execution of transmission prototype

One of the area of implementation of Rapid Prototyping techniques is production of research prototypes of gear transmissions. Figure 1 shows a chart of implementation of Rapid Prototyping in the production and research of polymer transmissions.

3D model built in CAD system, is required to production of prototype [11]. The CAD models can be created using different methods. The model can be built:

- *using technique of solid simulation of machining in CAD environment,*
- *based on mathematical models (e.g. equation of involute),*
- *using 3D scanner (in case of reconstruction).*

Because of specificity of gears and required accuracies, 3D scanning can be used mainly for identification of gear and then gear is modeled using one of the first two methods.

On the basis of CAD model, the gears models can be created using additive techniques of prototyping (such as stereolithography or fused deposition modeling – FDM). The two of many rapid prototyping techniques are chosen and differ in accuracy and durability of the model.

Stereolithography is the most accurate technique [14], [15], [16], [19]. In comparison with other techniques the SLA models are more accurate. However, the models are characterized by low mechanical resistant, so they are not usable for transmit the load and are only used as geometrical models or models using for preparation of prototypes in other methods. The cause of usage of SLA model as a prototype for vacuum casting, is high geometrical accuracy. Vacuum casting is applied to preparation of utilitarian prototypes, because of possibility of additional usage of different polymer materials for models. The other Rapid Prototyping techniques that can directly get test model, are also applied, exemplary FDM, however material and accurate limitations occur.

Exemplary CAD models of gears are show in the Figure 2a shows gears of planetary transmission and Figure 2b – gears of crossed transmission.

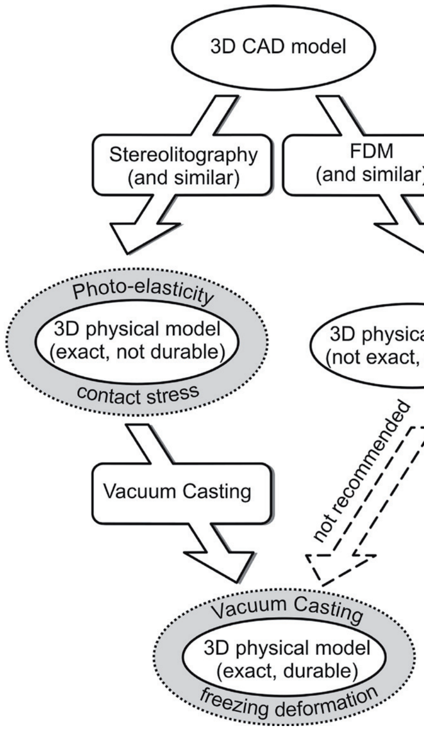


**Fig. 1:** *Distributions of rolling moments of scrapped rails heads in four roll passes, determined by FEM.*

On the basis of 3D CAD models are prepared the technology of model production using Rapid Prototyping. The screenshot from Lightyear programme shows the gears of planetary transmission – Figure 3.

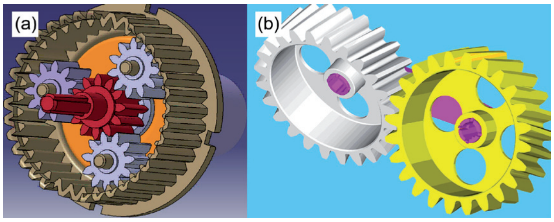


Fig. 2: *Using Rapid Prototyping techniques for prototyping and research of polymer gear transmissions.*

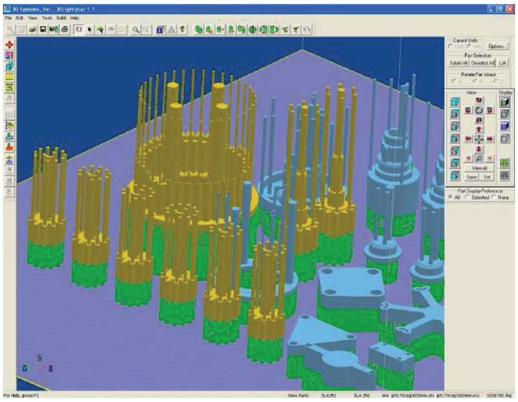

Fig. 3: *Elements of transmission prepared for formation.*

The gears are prepared for production in the stereolithographic apparatus. The hardening of layer in SLA-250 is shown in the figure 4. First the envelope of layer is hardened, then the cross-sectional area (exposure time set 30 seconds).

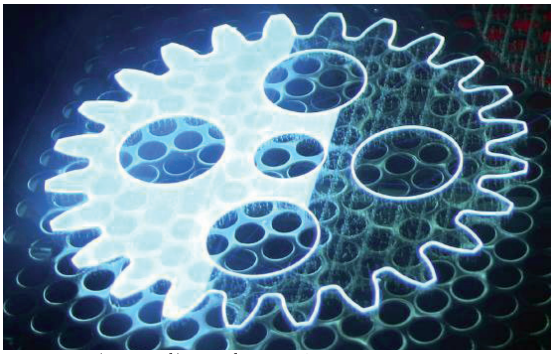

Fig. 4: *Hardening of layer of gear in SLA-250 apparatus.*

The finished gears models are show in the figure 5. Figure 5a shows models on platform of SLA-250 apparatus, 5b: gears after postprocessing set against in device as transmission.

In case of production of stereolithographic models made from resin that guarantees higher dimensional accuracy, the models are relatively low durable. The models are suitable for demonstration models or models for static research based on similarity principle. The stereolithographic material must be replaced with more durable in the case of research of materials similar to materials for real transmission. Vacuum casting is used in order to do such research. A wide range of polymers for usage is available. Such materials should be applied that have properties similar to target materials.

Figure 6 shows stereolithographic models prepared for vacuum casting. The models were prepared together with delivery and vent channels. The stereolithographic materials is transparent just like silicon used for mould matrix, so in order to split the forms, the selected surfaces were marked by color.

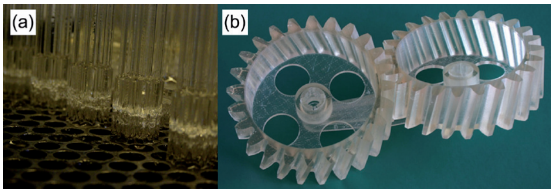


Fig. 5: *Physical gears models: a – in chamber of SLA-250, b – finished models.*

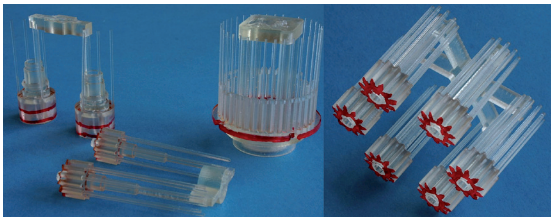

Fig. 6: *Stereolithographic models prepared for vacuum casting.*

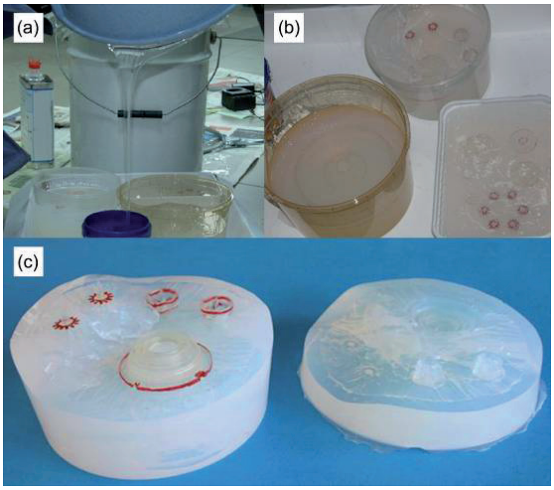


Fig. 7: *Formation of silicon mould matrix: a – pouring over matrix, b – poured matrices, c – finished and splitted matrix.*

The models were placed in right containers and poured over outgassed silicon (Figure 7), then outgassed again under very low pressure in the chamber of vacuum apparatus and crosslinked in the furnace. The finished, splitted multiple matrix is shown in the Figure 7c. The placement of a few small elements in the only one matrix accelerates process of prototyping significantly.

The casting process of utilitarian prototype in silicon form can be carried out in two ways:

*- casting of polymer in the chamber of vacuum apparatus (Figure 8a),*

*- low-pressure injection (Figure 8b).*

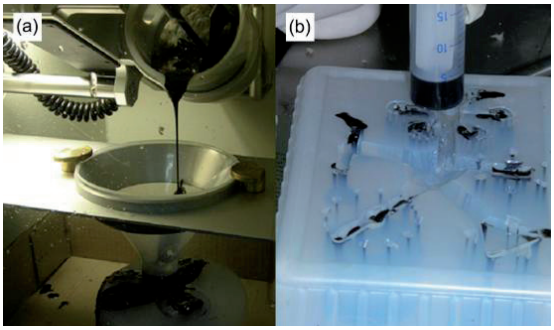


**Fig. 8:** *Filling the matrix: a – in vacuum, b – by low pressure injection.*

It is possible to production small series of prototypes, also made of different materials, because of multiple usage of silicon matrix. Figure 9 shows gears model made of polyurethane resin.

**Fig. 9:** *Polyurethane resin models after removal from matrix (visible delivery and vent channels).*

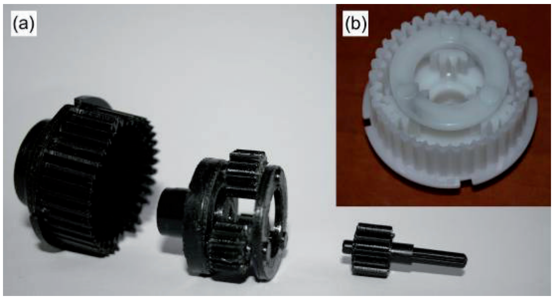


**Fig. 10:** *Planetary gear: a – prototype, b – mass-produce.*

Figure 10 a shows finished elements of transmission from figure 2a that are ready to utilization research, and figure 10b shows mass-produced transmission.

## 3. Usage of rapid prototyping techniques for research of transmissions

One of the advantages of stereolithography is possibility that models can be made of transparent resin. Additionally the resin SI5170 for gears has photo-optical properties. The material under load shows anisotropic properties that appear among other things as optical double refraction. That is way the material can be used in the experimental analysis of state of stresses and strains. The exemplary transmission loaded static moment is shown in the figure 11. The transmission was lit by polarized light and observed through a polarizing filter [10].

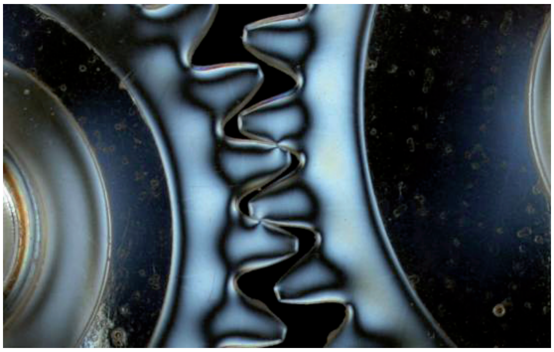

**Fig. 11:** *Using stereolithographic model in photo-elasticity*

The new area of usage of Rapid Prototyping techniques in research of gears is freezing deformation. The method consists in the placement of static loaded transmission in container and poured silicon with usage of vacuum casting. In this way the deformations are fixed. In case of gears it is very important to determine temporary tooth contact between teeth of loaded transmission at a given load. Figure 12a shows the fragment of crossed gear from figure 2b, made using stereolithographic technique. The transmission is prepared to load and poured over silicon. Figure 12b shows splitted matrix after removal one of the gears – the tooth contact that was fixed, is visible.

If gears are transparent (stereolithography), also the direct observation of tooth contact is possible – figure 13. In order to observe the tooth contact, the surface of model is moistened by detergent [5], [7], [8], [12], [17], [18].

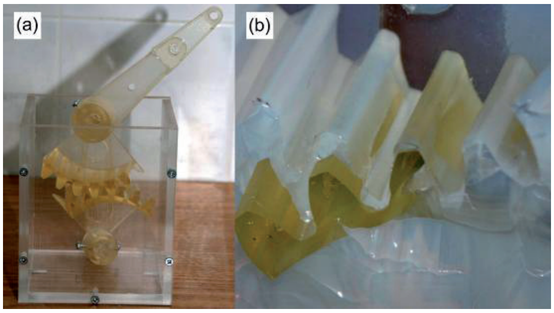


Fig. 12: *Freezing deformation: a – test model, b – splitted matrix.*

Fig. 13: *Direct observation of temporary tooth contact between teeth of loaded bevel gear pair (tooth contact – outline with dashed line).*

## 4. Conclusion

The Rapid Prototyping techniques are increasingly applied to production and research of gears prototypes. As shown in the article, Rapid Prototyping techniques are used in few fields connected with production and research of polymer transmissions. The techniques are used for:

*- production of prototype on basis of CAD model,*

*- production of prototype with usage of copy of existing model,*

*- photo-elastic research,*

*- research of tooth contact: direct observation or deformation freezing.*

Using Rapid Prototyping techniques, it is possible to shorten considerably the time of research of new types of transmissions made of plastics. In this case the transition from CAD model to physical prototype of gear lasts only a few days. In the case of production of polymer gears in the steel matrix, the time of transition form CAD model to first produced gear takes at least a few weeks, and the possible structural changes entail necessity of production of new matrix, so the costs are immensely increasing.

Using models from Rapid Prototyping, the production of small series of test gears is possible. The test gears can be distinguished by the geometry, and the best variant of gear can be chosen after research.

Using vacuum casting technique, the material with proper properties for geometry of transmission can be chosen.

The usage of optically active material enables to observe distribution of stresses in teeth of static loaded transmission. One of the main determinants of correctness of design of transmission is tooth contact occurred between teeth. As shown, Rapid Prototyping techniques allow to determine such tooth contact.

## 5. References

[1] Budzik G., Jaskólski J., Sobolak M., Rapid prototyping using in models building of engine elements, Journal of KONES Internal Combustion Engines, Institute of Aeronautics , Warszawa 2004, p. 282-287.

[2] Budzik G., Markowski T., Sobolak M., Analysis of Surface Roughness of Transmission Gear Teeth Made by Different Rapid Prototyping Methods, Journal of KONES Powertrain and Transport, Vol. 15, No. 2, Warszawa 2008, p. 29-34.

[3] Budzik G., Markowski T., Sobolak M., Nowe możliwości w projektowaniu kół zębatych wykonywanych z tworzyw sztucznych, Acta Mechanica Slovaca 2B/2006 PRO-TECH-MA, Košice 2006, p. 67-72.

[4] Budzik G., Markowski T., Sobolak M., Prototyping of Bevel Gears of Aircraft Power Transmission, Journal of KONES Powertrain and Transport, Vol. 14, No. 2, Warszawa 2007, p. 61-66.

[5] Budzik G., Markowski T., Sobolak M., Tooth contact analysis of hypoid gear transmission prototypes manufacturing with Vacuum Casting method, Journal of KONES Powertrain and Transport, Vol. 16, No 3 2009, p. 63-68.

[6] Budzik G., Sobolak M., Prototypowanie kół zębatych dla sprzętu AGD, XXII Sympozjon Podstaw Konstrukcji Maszyn Gdynia – Jurata, Tom 2, Wydawnictwo Fundacji Rozwoju Akademii Morskiej, Gdynia 2005, p. 145-150.

[7] Budzik G., Sobolak M., Eksperymentalne określanie chwilowego śladu styku w przekładni z wykorzystaniem szybkiego prototypowania, Zeszyty Naukowe Politechniki Rzeszowskiej 232, Mechanika z. 69 Koła zębate KZ 2006, Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów 2006, p. 221-226.

[8] Budzik G., Sobolak M., Experimental Method of Tooth Contact Analysis (TCA) With Rapid Prototyping (RP) Use, Rapid Prototyping Journal, Volume 14 Number 4, 2008, p. 197-201.

[9] Budzik G., Sobolak M., Prototypowanie kół zębatych z wykorzystaniem stereolitografii i odlewania próżniowego, Konferencja naukowo-techniczna: KZ 2004 Koła zębate 2004–Gears 2004, Rzeszów – Bezmiechowa, Zeszyty Naukowe Politechniki Rzeszowskiej nr 217, Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów 2004, p. 264-270.

[10] Budzik G., Sobolak M., Visualization of Internal Stress Pattern in Gears in Power Transmission System Using Rapid Prototyping (RP), Journal of KONES Powertrain and Transport, Vol. 15, No. 2, Warszawa 2008, p. 457-461.

[11] Jagiełowicz P., Advanced Technologies in Production Engineering - Generating 3D gears models for the rapid prototyping, Politechnika Lubelska, Lublin 2009, p. 67-72.

[12] Jagiełowicz P. E., Sobolak M., Experimental method of tooth contact analysis of loaded bevel gears with Rapid Prototyping use, PRO-TECH-MA Progressive Technologies and Materials, Rzeszów – Bezmiechowa 2009, p. 91-92.

[13] Jagiełowicz P. E., Sobolak M., Preliminary research of prototypes helical gears for power transmission systems, Journal of Kones Powertrain and Transport, Vol. 16, No. 3/2009, Warszawa 2009, p. 375-380.

[14] Miechowicz S., Sobolak M., Określenie przydatności stereolitografii do prototypowania kół zębatych, Konferencja naukowo-techniczna: KZ 2004 Koła zębate 2004–Gears 2004, Rzeszów – Bezmiechowa, Zeszyty Naukowe Politechniki Rzeszowskiej nr 217, Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów 2004, p. 271-277.

[15] Rejman E., Sobolak M., Method of increasing the accuracy of stereolitographical model, 1st International Conference Rapid Production 2004, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2004, p. 239-244.

[16] Rejman E., Sobolak M., Some aspects of accuracy and quality of the model surfaces produced in the stereolitography process, Fourth International Congress: Mechanical Engineering Technologies'04, Scientific Proceedings of the Scientific-Technical Union of Mechanical Engineering, Vol 4/72, September 2004,Varna, Bułgaria 2004, p. 152-155.

[17] Sobolak M., Eksperymentalna metoda określania chwilowego śladu styku w przekładni zębatej, Archiwum Technologii Maszyn i Automatyzacji, Vol. 27 nr 2, Poznań 2007, p. 161-167.

[18] Sobolak M., Eksperymentalna metoda określania chwilowego śladu styku w przekładni zębatej, Przegląd Mechaniczny, Nr 9/2007, p. 45-47.

[19] Sobolak M., Zastosowanie stereolitografii (SLA) w procesie wytworzenia elementów z tworzyw sztucznych, rozdział w monografii: Innowacyjne systemy wytwarzania i analizy produktu, Pr. zbiorowa pod red. Jeżowski J., Heneczkowski M., Oleksy M., Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów 2008, p. 97-123.