Knjiga povzetkov
Book of Abstracts

Fakulteta za tehnologijo polimerov
Faculty of Polymer Technology

Slovenj Gradec, Slovenija
17th – 18th June, 2021

FTPO Mednarodna konferenca 2021: Plastični zobniki

FTPO International conference: Plastic gears

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Fakulteta za tehnologijo polimerov, Ozare 19, 2380 Slovenj Gradec, Slovenija

Faculty of Polymer Technology, Ozare 19, 2380 Slovenj Gradec, Slovenia

Uredniki /Edited by:

Maja Mešl, Miroslav Huskić, Irena Pulko, Blaž Nardin

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Foreword

Plastic gears conference aims to bring together theorists, experimentalists and industrialists in the field of polymer gears research as well as applications. The conference will be held from 17th to 18th June 2021 at the Faculty of Polymer Technology (FTPO) in Slovenj Gradec, Slovenia. We hope to provide a venue for discussions between scientists and engineers from academia and industry, bridging fundamental and applied aspects of the polymeric gears.

Due to the unfortunate Covid-19 situation, the conference will be organised as a hybrid conference (online and onsite). The situation in Slovenia is getting better and we hope that it will be even better, in Slovenia as well as in other parts of the world. However, we suggest checking the status of your country and Slovenia frequently, to avoid unnecessary travelling complications.

We wish all the participants a pleasant stay in Slovenj Gradec and/or enjoying the scientific program!

Local Organising committee

The conference is organised within a project MAPgears: Advanced materials, methodologies and technologies for the development of lightweight power transmission components for drives technology. The project is co-funded by the Republic of Slovenia - Ministry of Education, Science and Sport - and the European Union – European Regional Development Fund.

MAPgears

REPUBLIKA SLOVENIJA
MINISTRSTVO ZA IZOBRAŽEVANJE, ZNANOST IN ŠPORT

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NALOŽBA V VAŠO PRIHODNOST

Scientific programme

Thursday, 17. 6. 2021

IL – Invited lecture, L - Lecture

8:30 – 9:00	Registration	
9:00 – 9:15	Opening ceremony	
9:15 – 9:30	Presentation of the Mapgears project	
	Session 1: Chair: Miroslav Huskić	
9:30 – 10:00	High Performance Plastic Gears – Recent Advances In Application And Research Karsten Stahl; Thomas Tobie, **Christoper Illenberger**	IL-1
10:00 – 10:30	Tooth form optimization of plastic gearsTooth form optimization of plastic gears **Aljaž Pogačnik**	IL-2
10:30 – 10:50	Tooth Contact Analysis Of Plastic Cylindrical Gear **de Vaujany Jean-Pierre**, Lagresle Charly, Guingand Michele, François Besson	L-1
10:50 – 11:10	Hertzian Contact Stress Analysis Of 3D Cylindrical Bodies Using Finite Element Method **Sugunesh A. P.**, Johnney Mertens A.	L-2
11:10 – 11:30	Coffee Break	
11:30 – 11:50	A Multi-Criteria Design And Optimization Of Polymer Gears **Jože Tavčar**, Borut Černe, Jože Duhovnik, Damijan Zorko	L-3
11:50 – 12:10	Investigation Of Pre-Mature Contact Of Asymmetric Polymer Spur Gear **Vignesh S.**, Johnney Mertens A.	L-4
12:10 – 12:30	Optimal Tooth Profile Design For High Performance Composite Gears Using Numerical Simulations And Material Tests **Denis S Vdovin**, Dmitriy V. Krasnov	L-5
12:30 – 12:50	Numerical Investigation On The Convective Heat Transfer Coefficient Of Polymer Spur And Helical Gears Miguel Barbera-Domingo, Raul Martinez-Cuenca, **Víctor Roda-Casanova**	L-6
12.50 – 14:00	Lunch break	
	Session 2: Chair: Jože Duhovnik	
14:00 – 14:30	Durability And Performance Of Autoclave-Cured Carbon Fiber Reinforced Polymer Composite Gears **Damijan Zorko**	IL-3
14:30 – 15:00	The Performance Enhancement Of Polymer Composite Gears And Their Applications In Lightweight Gearbox **Ken Mao**	IL-4
15:00 – 15:20	Effect of Compatibilizers on Surface Roughness, Mechanical, and Thermal Properties of Thermoplastic Composites with High Thermal Conductivity **Silvester Bolka**, Teja Pešl, Roman Christopher Kerschbaumer, Blaž Nardin	L-7
15:20 – 15:40	Wear Behavior Of Nylon And Nylon Composite Gears **Matija Hriberšek,** Simon Kulovec	L-8
15:40 – 16:40	Visit to FTPO labs	

18:00 – 22:00	Conference dinner	

Friday, 18. 6. 2021

8:30 – 9:00	Registration	
	Session 3: Chair: Stefano Montani	
9:00 – 9:30	Bending Fatigue Performance Of Polymer Gears **Selvaraj Senthilvelan**	IL-5
9:30 – 10:00	Hybrid Polymer Gears: Context, Modelling And Preliminary Validation **Carlos Fernandes**	IL-4
10:00 – 10:20	Basalt Fibres As An Alternative To Glass Fibres In Reinforcing Polyamides For Tribological Applications **Rebeka Lorber**, Silvester Bolka, Blaž Nardin, Andreas Hausberger, Miroslav Huskić	L-9
10:20 – 10:40	Application Of Moldflow Simulation In Injection Molding Of Plastic Gears Andrej Glojek, Bojan Podpečan, **Matjaž Milfelner**	L-10
10:40 – 11:00	Noise Evaluation Of S-Polymer Gears **Boštjan Trobentar,** Matija Hriberšek, Simon Kulovec, Srečko Glodež, Aleš Belšak	L-11
11:00 – 11:30	Coffee Break	
11:30 – 11:50	Thermal Behaviour Of Polymer Spur Gears During Running–A Comprehensive Analysis Using Numerical And Experimental Approaches **Borut Černe**	L-12
11:50 – 12:10	Wear Behaviour Of Coated Polymer Gears **Brigita Polanec**, Frančišek Tašner, Srečko Glodež	L-13
12:10 – 12:30	Influence Of Rotational Speed On The Gear Mesh Stiffness Of A Polymer-Metallic Spur Gear System **Ala Eddin Chakroun**, Ahmed Hammami, Ana De-Juan, Fakher Chaari, Alfonso Fernandez, Fernando Viadero, Mohamed Haddar	L-14
12:30 – 12:50	The Tribology And Surface Thermal Behavior Of Tooth Flank Of Non-Metallic Gear: The Case Of Dry Running **Khalid Abdulkhaliq M. Alharbi**	L-15
12.50 – 14:00	Lunch break	
	Session 4: Chair: Miroslav Huskić	
14:00 – 14:30	Challenges for Gear Contacts in Polymer Tribology **Andreas Hausberger**	IL-7
14:30 – 15:00	Peek Gears For High Power Transmissions **Philipp Kilian**, Karl Kuhmann	IL-8
15:00 – 15:20	Specialty Polymers for High Performance Gears **Stefano Montani**, Rodolfo Patricio	L-16
15:20 – 15:40	Use of plastic gears in hydraulic pumps **Michał Banaś**, Jarosław Stryczek, Sławomir Bednarczyk, Krzysztof Biernacki	L-17
15:40 – 15:55	Closing ceremony	

High Performance Plastic Gears – Recent Advances In Application And Research

Stahl, K.; Tobie, T., Illenberger, C.
Technical University of Munich Germany
stahl@fzg.mw.tum.de

Plastic gears have been used for decades in a wide variety of applications such as consumer articles or electromechanical actuators in the automotive sector. Plastic specific material properties such as low density and high damping characteristics as well as the possibility of mass production through injection molding are advantageous and contribute to the increasing application of plastic gears. However, the comparatively large differences in material properties compared to steel result in plastic gears mostly being used in low-power drives. In particular, the high temperature dependency of the material properties and lower strength numbers often represent a challenge for the application of plastic gears.
Current research provides new knowledge on the operating behavior and the load carrying capacity of modern thermoplastic materials and contributes to the optimized design of plastic gears. This presentation gives an overview of the state of the art and application of plastic gears, introduces existing design and calculation methods for plastic gears and summarizes main results of recent research work performed at FZG institute.

Tooth form optimization of plastic gears

A. Pogačnik[1], U. Kissling[2]
[1]*Bauhar s.p., Bled, Slovenia*
[2]*KISSsoft AG, Bubikon, Switzerland*

When designing plastic gears, which will be produced using injection moulding, engineers are not limited by the traditional gear manufacturing methods like hobbing and grinding. This gives engineers freedom to further optimize the tooth form to improve the strength, noise or wear behaviour, but at the same time keep the price of the gears low. The presentation will provide an overview on different methods that are commonly used in the optimization process of plastic gears.

The quality of injection moulded plastic gears is usually ISO 10 or 11, which is much lower compared to the quality of steel gears (ISO 6 or 7). A consequence of lower quality of plastic gears, combined also with higher tooth deflection, is usually a noise increase, which is simply not acceptable in modern gear designs. To lower the noise footprint of the gears, tooth form can be optimized using profile or flank line modifications (tip relief, profile crowning, …) or also using deep tooth form, where contact ratio is > 2.0.

The root strength of plastic gears can be improved by changing the root area of the gear (using elliptic root modification or full rounding), which results in lower tooth root stresses and higher lifetime. For combinations of steel/plastic gears, the tooth thickness modification is also often applied.

The flank strength of dry running plastic gears is usually checked through the wear safety factor calculation. By selecting proper profile shift in combination with profile modifications, the total wear on the gears can be significantly improved.

Advantages of special gear designs (asymmetric, non-circular) are also briefly discussed.

Durability And Performance Of Autoclave-Cured Carbon Fiber Reinforced Polymer Composite Gears

Damijan Zorko, University of Ljubljana, Faculty of Mechanical Engineering, LECAD
Aškerčeva 6, 1000 Ljubljana
damijan.zorko@lecad.fs.uni-lj.si

A material must exhibit good fatigue strength and favorable tribological properties such as good wear resistance and low coefficient of friction for use in gear applications. Laminated composites have so far received little attention as a potential material for gear drive applications. Gears made from an autoclave cured woven carbon/epoxy composite are potentially interesting for use in demanding applications where low weight, small volume, low noise and high performance are important, e.g. in the automotive and aerospace sectors. Such gears can operate without additional lubrication, which makes them interesting for applications where lubrication is not desirable or difficult to provide. The performance of woven CFRP gears is worth investigating due to their high potential to further increase load bearing capacity and wear resistance as compared to short fiber reinforced polymer gears. More research would expand the range of potential applications in order to fill in the large gap between the metal and polymer gears.
The potential of autoclave cured woven carbon fiber reinforced polymer (CFRP) composite gears was thoroughly investigated. Test gears of size m = 1 mm, z = 20, b = 2 mm were milled from a high-quality, autoclave cured, woven carbon fiber reinforced epoxy composite plate and tested in mesh with a steel pinion. All tests were conducted in unlubricated conditions under torque load ranging between 0.4 Nm and 0.8 Nm and a rotational speed of 1400 rpm. The nominal gear surface temperature was measured during testing with a thermal camera. The damage on gears was monitored every 2 million cycles of testing using a high-resolution optical digital microscope. Five such intervals were conducted and, after reaching 10 million cycles, the gears were run until failure.
Failure mechanisms were studied employing a scanning electron microscope (SEM) and a high-resolution optical microscope. The final gear failure occurred after a long operating period of progressive fatigue damage and abrasive wear. The relationship between wear volume against the number of cycles was obtained. Scanning electron microscopy revealed two- and three-body abrasive, oxidative, and fatigue wear, and progressive de-laminations during the sliding and rolling of the gears. Epoxy matrix micro-cracking was found as the damage mechanism which led to the final delamination failure. The performance of CFRP gears was compared with the best polymer and polymer-composite high-performance gears available and a significantly longer lifespan of laminated CFRP gears was observed.

Acknowledgement
This research was financed partly by the MAPgears project (the project is co-financed by the Republic of Slovenia and the European Union under the European Regional Development Fund, contract no. C3330-18-952014) and partly by the Slovenian Research Agency (contract no. 630-33/2019-1).

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The Performance Enhancement Of Polymer Composite Gears And Their Applications In Lightweight Gearbox

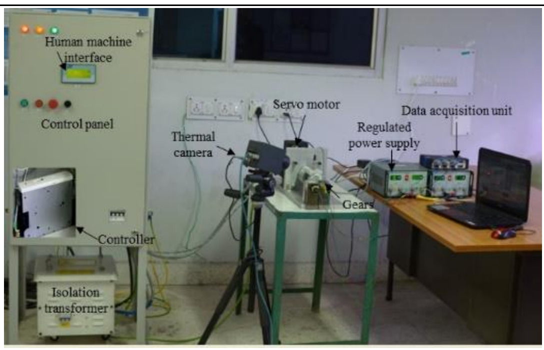
Ken Mao
University of Warwick, School of Engineering, Great Britain
K.Mao@warwick.ac.uk

The presentation will summarise some of the polymer gear research progress in Warwick University, especially the gear performance enhancement. The polymer gear test methods will be briefly introduced firstly, which includes its two unique approaches, i.e. recording gear surface wear continuously and gear misalignment engagement. Three main manufacturing methods for polymer composite gears will be discussed, i.e. machine cut, injection moulding and 3D printing. Also, those gears performances will be examined and discussed against each manufacturing methods. Finally, some of those gear applications in lightweight gearbox design will be briefly described including EV and motorbike.
Advantages of special gear designs (asymmetric, non-circular) are also briefly discussed.

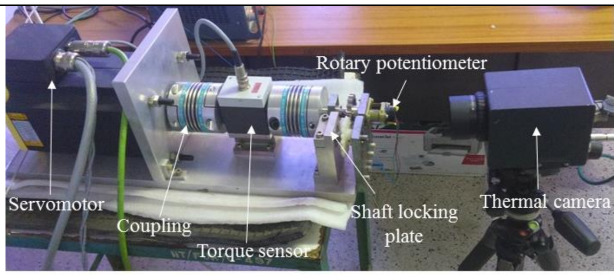
Bending Fatigue Performance Of Polymer Gears

S. Senthilvelan,
Indian Institute of Technology Guwahati, India
ssvelan@iitg.ac.in

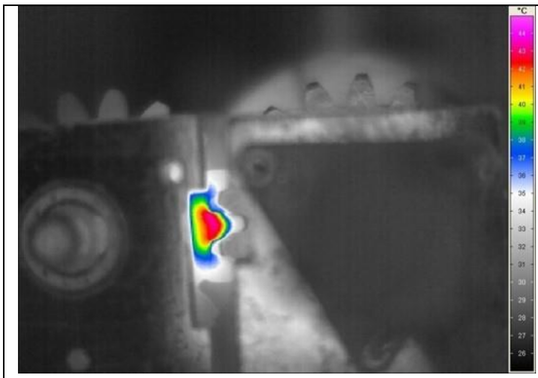
Polymer and polymer composite gears are now-a-days considered for medium torque applications. Bending fatigue of polymer composite gears become important in bi-direction applications such as robotics, actuators of satellite launchers, etc., due to their lower mechanical and inferior thermal properties. The test rig consisted of the loading system, control panel, thermal camera and data acquisition. Bi-directional (R=-1) and uni-directional (R=0) torque load (7-12 Nm) tests were performed at 5 Hz and 10 Hz respectively using the gear test rig. A servo motor (BALDOR, USA) driven gear test rig simulating actual gear mesh condition was developed in-house and was used to evaluate the bending fatigue performance.



In-house developed gear test rig



Close up view of gear test rig



Thermograph of PA gear subjected to bi-directional 7 Nm load

Root crack of PA gear showing straight crack: bi-directional 7.5 Nm load

Hybrid Polymer Gears: Context, Modelling And Preliminary Validation

Carlos M.C.G. Fernandes
FEUP, Universidade do Porto, Rua Dr. Roberto Frias s/n, 4200-465 Porto, Portugal
cfernandes@fe.up.pt

A drawback of polymer materials is their low thermal conductivity which affects the operating temperature of polymer gears. The mechanical properties of polymer gears are critically dependent on the maximum operating temperature.

Several solutions to improve thermo-mechanical behaviour and load capacity of polymer gears have been proposed in the literature [1, 2]. The author focused his research into two main approaches: (1) use of low loss gear geometries [3] and (2) a hybrid polymer gear concept in order to improve the thermal evacuation of the meshing gear tooth [4]. Both methodologies may result in several manufacturing challenges that need to be overcome.

The first solution (1) was studied using FZG tests that proved that the operating fatigue life of the gear is improved using a low loss geometry in comparison with a spur gear. The low loss helical gear geometry reached a life span 3 times longer than the reference spur gear without failure [5].

The study of the second solution (2) was mostly based on a FEM model [6], which was later validated with experiments. The simulations showed that the spur polymer gear with an aluminum insert is able to decrease the bulk temperature by 28 % while the mass is increased by 9 %. Based on a recently developed testing device, the thermal behaviour of different hybrid polymer gear geometries was accessed. The preliminary results were gathered using different cooling strategies: air, water and inserted materials.

Acknowledgement

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Challenges for Gear Contacts in Polymer Testing

A. Hausberger[1], T. Stiller[1], M. Tockner[1], G. Pinter[2], F. Summer[3], F. Grün[3]
Polymer Competence Center Leoben GmbH, Roseggerstraße 12, 8700 Leoben, AT
Chair of Materials Science and Testing of Polymers, Otto-Glöckel Str. 2, 8700 Leoben, AT
Chair of Mechanical Engineering. Franz-Josef Str. 18, 8700 Leoben, AT
Andreas.Hausberger@pccl.at

With respect to gears the trend of mass production and a simultaneous weight reduction, polymers found their way into applications. Additional benefits leading to this success are the significant noise reduction and the resistance to corrosion. Nevertheless, big drawbacks of polymer gears are the temperature limits and viscoelastic properties, which can cause a failure of the final product.

From a historical point of view, the typical testing methods for metals were transferred and adapted to the special needs for polymers. A challenging task is still to adapt the existing metal-based gear systems with polymer-based systems. In addition to the limitation by temperature, one goal is to achieve a comparable load capacity compared to metals. For a first attempt tribological model-test are often realized with Pin-on-Disc setups. Considering a gear, the movement is a combination of sliding and rolling, which is not well represented in a simple sliding Pin-on-Disc test. A possibility is to test besides the sliding friction also the rolling friction in a two-disc-setup. Nevertheless, the obtained results can't easily be combined to estimate the damage in a gear. The correlation has to follow the concept of damage equivalent, which shows that the damages in the model test are comparable to the one in the real application. As a case study a series with a reinforced polymer matrix (e.g. with glass fibers, PTFE, bronze etc.) is investigated with different tribological test setups. As it is well known that the tribological values are system values and not material values, which strongly depend on the tribological system. The study shows that already a slightly changed geometry with apart from that unvaried parameters leads to a significant difference in the tribological behavior. Furthermore, it revealed the impact of motion (rotating or reciprocating) as well as the real area of the tribological stressed contact. Overall the precise control and measurement of temperature turned out to be the most crucial factor for the system. The trends can diverge if one system keeps precisely the contact at a temperature, whereas the other system only keeps the temperature for the temperature chamber.

Generally speaking an optimized gear system requires consideration of the whole tribological system as shown in the case study for different tribological setups. This counts for well-known materials and technologies.

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Peek Gears For High Power Transmissions

Philipp Kilian,[1] Karl Kuhmann[2]
[1] Head of Tribology Development, *High Performance Polymers, Evonik Operations GmbH, Darmstadt*
[2] Director Polymer Technology Development, *High Performance Polymers, Evonik Operations GmbH, Marl*
philipp.kilian@evonik.com

High performance polymers have attracted increasing interest for tribological applications due to high operational temperatures combined with high strength, wear resistance and low coefficient of friction. The use of plastic gears whether in AdBlue or oil pumps, mass-balancing differentials, electric engines or sensor systems for car interiors is steadily increasing mainly due to benefits e.g. reduced noise (NVH), weight and production costs. This calls for the development of gear systems that can operate in dry and lubricated conditions, not just in vehicles, but also in industrial or future mobility applications. Polyetheretherketone (PEEK) provides a unique combination of mechanical properties, resistance to chemicals, wear, fatigue and creep as well as exceptionally high temperature resistance. Evonik offers several molding compounds that have been used for high-performance gears for years, including the reinforced and unreinforced PEEK molding compounds VESTAKEEP®. The appropriate modification with additives leads to improved tribological properties of polymeric materials. Since the behaviour of polymers depends on various properties (e.g. thermal and/or mechanical), the right material selection for specific tribological applications is a complex task. Therefore, VESTAKEEP® results in screening and gear rig tests are shown. Dry running and lubricated plastic gear S/N curves and wear coefficient data as well as effects of different test parameters (e.g. load, temperature and velocity) are discussed. Examples of VESTAKEEP® gears demonstrate attractive technical opportunities for these interesting materials.

Tooth Contact Analysis Of Plastic Cylindrical Gear

de Vaujany Jean-Pierre *, Lagresle Charly **, Guingand Michele *, François Besson**
* Univ Lyon, INSA Lyon, CNRS, LaMCoS, UMR5259, 69621 Villeurbanne, France
** Mecalam, CEI, 66 bd Niels Bohr - CS 52132, 69603 Villeurbanne, France
Jean-Pierre.Devaujany@insa-lyon.fr

The LaMCoS Laboratory has developed original models to simulate the quasi-static loaded behavior of several types of gears (cylindrical, spiral, worm gear, face gear, pinion rack) for decades [1] [2] [3]. The material can be metallic or plastic. In case of polyamide gears, the considered contact can be plastic-metal (worm gear) or plastic-plastic (cylindrical gear). For these gears, the case of polyamide with glass fibers has been studied [4]. The proposed paper will describe the polyamide cylindrical gear model developed by the LaMCoS Laboratory and its improvements achieved by Mecalam, a young company created in June 2015. Mecalam is positioned at the interface between research and industry in the field of power transmissions by meshing systems.
With the help of mechanical characterization, a linear rheological generalized Kelvin-Voigt model was developed to simulate the viscoelastic behavior of the material. This model considers temperature, humidity, and rotation speed. It has been integrated in the quasi-static load sharing computation developed by the LaMCoS laboratory. In the calculus, the displacements are obtained on a large meshing covering the entire surface of the tooth. The viscoelastic displacement and the geometrical influence coefficients are considered in the model. These influence coefficients are obtained with a unique FEM computation and the use of a special set of functions. With this process, the model takes into account the environment of the meshing such as axis misalignment, bearing stiffness… The method provides results such as the loaded transmission error, the instantaneous meshing stiffness within a reasonable computation time. The model can detect abnormal contacts that are not located in the meshing plane and it has been validated with measurements, carried out on an original test bench.
In this context, the initial software has been entirely rewritten by Mecalam. A Python-based demonstrator computing the quasi-static load-sharing has been created. New functionalities have been added. For example, to construct the Kelvin-Voigt model, multiple DMA test processes are used to obtain the viscoelastic mechanical properties of the polymer for a short range of frequencies and for given temperatures. The experimental data are now automatically sorted and cleaned by a k-means sorting algorithm and extrapolated above the experimental frequencies range according to the time-temperature superposition principle. Fitted models characterizing the storage modulus and the loss modulus are fitted to the experimental data with methods using the combinations of polynomial, gaussian and step models.

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Hertzian Contact Stress Analysis Of 3D Cylindrical Bodies Using Finite Element Method

Sugunesh A P[1], Johnney Mertens A[2*]
Research scholar, Department of Mechanical Engineering, National Institute of Technology Puducherry
**Assistant Professor, Department of Mechanical Engineering, National Institute of Technology Puducherry*
suguneshap@gmail.com

Rotary machine elements such as gears, cams, and bearings are most commonly employed in power transmission mechanisms. Such machine elements experience Hertzian contact stresses at the time of contact during power transmission. Hertzian contact stress develops at the contact point of two curved surfaces at the time of mating. A finite element tool like ANSYS is used to compute the contact stresses. In order to reduce the computational time and storage, 2D contact stress analysis was carried out with either plane stress or plane strain conditions. Diameter to thickness (d/t) ratio contributes to determining those conditions. But, very limited investigations were carried out to identify the transition region of the (d/t) ratio. In this work, 3D finite element analysis was carried out to evaluate the contact stresses developed in the two mating identical cylindrical bodies with varying thickness. A 20 mm diameter of identical cylindrical bodies was utilized for analysis with a load of 5000 N. Using appropriate boundary conditions, the contour stress patterns were studied to identify the transition region of the (d/t) ratio from plane stress to plane strain condition.

Keywords: 3D FEA; Plane stress; Plane strain; Hertzian contact stress.

A Multi-Criteria Design And Optimization Of Polymer Gears

Jože Tavčar[1*], Borut Černe[2], Jože Duhovnik[2], Damijan Zorko[2]
[1]*Lund University, Faculty of Engineering - LTH, Design Science, Lund, Sweden*
[2]*University of Ljubljana, Faculty of Mechanical Engineering, LECAD, Ljubljana, Slovenia*
joze.tavcar@design.lth.se[*]

A design and optimization of polymer gears remains an open challenge, due to the lack of polymer specific material data and to the complex relations between different geometric and operating parameters. The optimization algorithm was developed, which enables variation of geometry according to different criteria: the number of teeth (z_1, z_2), normal module (m_n), helix angle (β), and face width (b) for spur and helical gears. The method enables a better insight into how design parameters influence the target criteria. Additionally, a multi-criteria function and optimization procedure that enables a simultaneous consideration of different criteria such as root/flank stress, gear bulk/flank temperature, wear, deformation, quality, cost, and volume was developed [4]. The authors developed the OptiTooth software, which proof the applicability of the multi-criteria function in polymer gear optimization. Polymer gear design guidelines and rules accelerate the initial selection of the parameters and enable better overview over possible improvement options during the optimization process.
Polymer gears fail due to different failure modes. The main types of failure include temperature-induced failure, wear, and fatigue [1], [3]. The types of polymer-gear failures can vary depending on the operating conditions – which in turn define the acting loads, the gear geometry, the material pairing, and the chosen type of lubrication. For example, an identical material pair at a relatively high load will fail due to an excessive temperature load, while at a lower load it will fail due to wear, and in the event of lubrication it might fail due to fatigue, i.e. tooth fracture. Due to the large variation of materials, mechanical characteristics, tribological conditions, and thermal conductivity, the failure behavior of polymer gears is very diverse. Failure modes depend on the load level, number of load cycles, lubrications, speed of rotation, material pair, and method of interrelation. Relationships between design criteria and failure modes were investigated. A better understanding of sensitivity on design criteria and failure modes is crucial for a successful optimization. One of the finding is that a larger normal module reduces root stress linearly, but at the same time bulk temperature increases. The bending strength of polymer gears increases with a higher number of teeth due to load-induced deflection [2]. Therefore, if gear diameter is unchanged, a higher number of teeth with a smaller module can result in better performance than larger module with a lower number of teeth. Sensitivity analyses have shown that the pinion is critical for the temperature, and therefore using a metal pinion is often a recommended design solution.
Required polymer material data is a must for accurate gear design and optimization, therefore, the authors' research is now focused on the testing of promising material pairs and collecting specific material data.

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Investigation Of Pre-Mature Contact Of Asymmetric Polymer Spur Gear

Vignesh S[1], Johnney Mertens A[2*]
Research scholar, Department of Mechanical Engineering, National Institute of Technology - Puducherry
**Assistant Professor, Department of Mechanical Engineering, National Institute of Technology - Puducherry*
vickytechie03@gmail.com

The advancement of polymer science has made it possible to use polymers instead of metal in power transmission systems. Reduced weight, improved corrosive resistance, and the ability to operate without lubrication are all benefits of using polymer gears. However, such gears are sensitive to high temperature and are only suitable for low-duty and medium-duty applications. To overcome this, asymmetric gearing is being considered to improve the strength of polymer gears having uni-directional functionalities. Because of the asymmetric gear configuration, the drive side tooth flank can be designed independently from the coast side tooth flank. It decreases the cantilever effective length of the gear tooth which will improve the load-carrying capability. However, polymer gears exhibit a pre-mature extension of contact at the beginning and ending of gear tooth meshing. This pre-mature extension induces high contact stress at the pitch point region because of the contact between the driven gear tip and the driver gear pitch point. This extended contact's effect on the performance of asymmetric polymer gears has yet to be explored. In this study, a kinematic analysis was performed for both symmetric and asymmetric polymer gears by using finite element analysis software ANSYS. The effect of extended contact on bending stresses and roll angle was investigated, and the findings were compared to those obtained with conventional metal gears.

Optimal Tooth Profile Design For High Performance Composite Gears Using Numerical Simulations And Material Tests

Vdovin D.S.[1], Krasnov D.V.[2]
[1]*Bauman MOSCOW STATE TECHNICAL UNIVERSITY*
[2] Scientific and Technical Center «Drive Technique»
vdovin@bmstu.ru

Existing analytic optimization and calculation methods for plastic and composite gears, described in standards like VDI 2736, VDI 2545, etc., has some limitations, which could be overcome by using numerical simulations - finite element analysis. Effects like load sharing among neighbor teeth, contact patch stress distribution, temperature field and temperature-dependent nonlinear stiffness in tooth bulk could be captured with greater precision using accurate finite element models as compared to analytic formulas for plastic gears, that usually adopted from steel gears calculation methods. Analytic prediction still could be used for rough predictions in gear tooth profile optimization process. Another difficulty in composite gears design process – is the lack of material properties data. In practice, it is almost never possible to get full necessary data of composite or plastic material behavior from supplier of public sources.

Modern thermo-resistant polymers, like PPS, PEEK, PA46, PPSU with anti-friction and high thermal conductivity additives and carbon/glass/aramid fibers reinforcement are the most promising materials for high-loaded composite gears in automotive, aerospace and other applications. Main advantages are lower noise and vibration, no lubricant use, low mass and inertia, low cost in mass production. In this work, several engineering composites were investigated for their wear rate and heat generation in friction conditions, corresponding to friction conditions in gears of convenient all-purpose one-stage geared motor. In addition, thermal-dependent stress-strain curves and fatigue properties of these materials were evaluated from mechanical experiments. Gained material data used for optimization of tooth profile. Gears with optimized profile were produced by injection molding process. Then gears were tested in the geared motor.

Test results and verification calculations shows that composite gears, compared to steel gears of the same size, can transmit up to 70% of steel gears power during quasi-static or periodic loads (with no significant heat generation) and 25…35% of power during long-term continuous duty cycle with no lubricant. Neighbor teeth load sharing in composite gears increased vs steel gears: peak loads are 10…30% lower in composite gears due to low material stiffness and bigger gear widths design is also possible for composites. Pinion should preferably be made of steel, gear – of composite: this way one can obtain smaller size vs pure plastic-plastic gears meshing. Also plastic-plastic contact in dry work or in water as lubricant is not worthy: wear usually too high. Injection molding allow use non-involute optimized profile for gear. Custom hub and grinding still needed for the steel pinion production process, but heat treatment not needed.

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Numerical Investigation On The Convective Heat Transfer Coefficient Of Polymer Spur And Helical Gears

Miguel Barbera-Domingo[1], Raul Martinez-Cuenca[1], Víctor Roda-Casanova[1], Francisco Sanchez-Marin[1], Sergio Chiva[1]
Department of Mechanical Engineering and Construction, Universitat Jaume I, Spain
vroda@uji.es

The determination of their operating temperature is an important step during the design stages of polymer gears. In the early years, several analytical methods were developed for such a purpose [1,2]. In the great majority of them, the body of the gears is modeled as a point mass (by assuming a uniform temperature through the gears) and the zeroth law of thermodynamics is used to calculate their equilibrium temperature, considering the heat generated by friction and the heat dissipated by convection. However, as the polymer gear technology advanced and the requisites for the polymer gears increased, enhanced methods were required to determine the temperature field along the gear bodies. In this line, several numerical methods have been developed that rely on a thermal finite element analysis of the gears, where the frictional heat generation is considered through a movable heat flux function [3, 4, 5]. In the great majority of these methods, convective heat transfer is considered through surface film conditions, which are applied to the external surfaces of the gear body and are characterized by the ambient temperature and a convective heat transfer coefficient. These heat transfer coefficients are usually calculated by approaching the gears bodies to simple geometrical objects (i.e. rotating disks, rotating plates, etc.), and then using the empirical equations that have been derived for them. These methods have been used to predict the temperature field of polymer spur gears, and they have been validated by experimental means [4, 5], indicating that convective cooling is successfully modeled.
In order to gain insight about the convective cooling of polymer gears, improved methods are required. In this work, Computational Fluid Dynamics (Element-based Finite Volume Method [6]) are used to solve the turbulent flow (SST model [7]) surrounding the rotating polymer gears and to determine the heat transfer coefficient for their surfaces. In the proposed method, the actual geometry of the gears, their kinematics and heat transfer are considered. The proposed method is illustrated with numerical examples corresponding to spur and helical gears, and the results are compared to those obtained from the empirical equations typically used for such a purpose, showing global agreement between them.

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Effect of Compatibilizers on Surface Roughness, Mechanical, and Thermal Properties of Thermoplastic Composites with High Thermal Conductivity

Silvester Bolka[1*], Teja Pešl[1], Roman Christopher Kerschbaumer[2], Blaž Nardin[1]
Faculty of polymer technology, Ozare 19, 2380 Slovenj Gradec, Slovenia
Polymer Competence Center Leoben GmbH, Roseggerstrasse 12, 8700 Leoben, Austria
**silvester.bolka@ftpo.eu*

In injection moulded gears, friction is one of the most important characteristics, in addition to the size of the parts. Friction causes wear and heating of the gears. One of the most influential factors on friction and hence heating of gears is the surface roughness of the gears. To avoid failures due to heating and friction, thermoplastic composites with high thermal conductivity can be used. In addition to high thermal conductivity, strength and stiffness are also required while maintaining toughness.
In this paper, the in-house produced thermoplastic composites filled with boron nitride are presented. Polycarbonate was used as the thermoplastic matrix due to its low shrinkage. In order to achieve a good combination of thermal, mechanical, and tribological properties, the composites were modified with different types of compatibilizers. In the case of the compatibilizer, two approaches were studied. The first with good interactions with polycarbonate resins to obtain the highest strength and stiffness, the second to obtain the best toughness. Complementary to the mechanical properties, the surface roughness was characterized. In addition, to improving the surface interactions of the filler and matrix, the compatibilizer also affects the thermal conductivity and surface roughness of the injection moulded parts. Various combinations of very high thermal conductivity and lower surface roughness were obtained in the produced composites with the addition of different compatibilizers compared to composites without compatibilizer. Besides the influence on the tribological properties, the differences on the mechanical properties were even more evident. The dynamic mechanical analysis showed very high heat deflection temperatures, but not directly related to the level of the storage modulus. Moreover, the prepared compounds could be a good alternative material for polymeric gears, especially as a combination of gear pairs, due to different combinations of surface roughness, thermal conductivity, strength, stiffness, and glass transition temperature.

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Wear Behavior Of Nylon And Nylon Composite Gears

Matija Hriberšek[1], Simon Kulovec[2]
Podkrižnik d.o.o., Loke 33, 3333 Ljubno ob Savinji
matija.hribersek@podkriznik.si

The use of plastic gears depends on the application and its basic requirements. To perform precise optimization of power transmission system, the engineers must determine the right mating gear pairs which will provide the best mechanical, tribological and wear characteristics of the observed system. In recent years, there has been increased progress in the development of lightweight polymers and composites suitable for gear applications. There are mainly POM, PA PEEK, PBT, HDPE. In this research, steel/ nylon gear pairs are observed. There are researched two types of materials: nylon 66 and nylon 66 composite material reinforced with glass fibers and internal lubricant Polytetrafluoroethylene. Failure mode of generic nylon in compare to composite material are explained. Basic operating characteristics are defined, such as operating gear temperatures, wear coefficients and S-N lines and compare to current literature with aim to improve database for mentioned materials and enable engineers more precise calculation procedure.

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Basalt Fibres As An Alternative To Glass Fibres In Reinforcing Polyamides For Tribological Applications

Rebeka Lorber[1], Silvester Bolka[1], Blaž Nardin[1], Andreas Hausberger[2], József Gábor Kovács[3], Miroslav Huskić[1]
[1] *Faculty of Polymer Technology*
[2] *Polymer competence centre Leoben*
[3] *Department of Polymer Engineering, Faculty of Mechanical Engineering Budapest University of Technology and Economics*
rebeka.lorber@ftpo.eu

In light of dealing with emerging environmental concerns, greener alternatives are becoming more attractive for both research and mass production. Basalt fibres are known for their good mechanical and thermal properties, which in most cases exceed those of A-glass fibres. The raw material is basically available in unlimited quantities and the production is less energy consuming compared to glass fibre. The use of glass fibre reinforced polymers in tribological applications is well known, but basalt fibre is not nearly as well known. With this in mind, 9 composites based on polyamide 6 were prepared using a twin-screw extruder. The composites were reinforced with either 30% glass fibres or basalt fibres. To investigate the effects and interactions of the reinforcement with the internal lubricant, three of the compounds contained an additional 15% PTFE. An adhesion promoter was added to most of the compounds to improve the interactions at the interface between matrix and fibre, and each compound was stabilised with an antioxidant. The prepared composites were injection moulded into test specimens according to standard moulds ISO 527 (type 1BA), ISO 178, and ISO 179. Mechanical properties were determined by tensile, flexural and impact tests, thermal properties by dynamic scanning calorimetry (DSC) and thermogravimetric analysis (TGA), thermal conductivity by HotDisk and tribological properties by pin-on-disc method. Tensile tests were also carried out at 7 different temperatures ranging from 20 °C to 80 °C with 10 °C steps in between. The fabricated glass fibre reinforced composites were slightly stiffer, stronger, tougher and more resistant to thermal degradation than comparable basalt fibre reinforced materials. However, basalt fibre reinforced composites tend to retain more of their tensile modulus at elevated temperatures than comparable glass fibre reinforced materials. Tribological properties were comparable for both basalt and glass fibre reinforced PA6. The addition of PTFE had no significant effect on the coefficient of friction, but significantly lowered the wear rates. The bonding agent had a similar effect with respect to the coefficient of friction, while it lowered the wear rate of the basalt fibre reinforced composites and increased that of the glass fibre reinforced composites. Overall, the basalt fibres showed their potential to be used as an alternative to glass fibres for reinforcing polyamides, also and especially in tribological applications.

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Application Of Moldflow Simulation In Injection Molding Of Plastic Gears

Andrej Glojek, Bojan Podpečan, Matjaž Milfelner
TECOS, Slovenian Tool and Die Development Centre, Kidričeva ulica 25, SI-3000 Celje, Slovenia
matjaz.milfelner@tecos.si

Injection molding is one of the most common processes to produce plastic parts, from simple to complicated. This paper focuses on an application of Moldflow simulation to optimize the injection molding process of various designs of plastic gears. Based on the results of the simulation, the most suitable design will be selected.
The aim of the numerical simulations is to develop the optimal design of the mold and process parameters for the gear SIZE 1 according to VDI 2736, with which it will be possible to achieve the best possible dimensional accuracy of the plastic gears, which is most important for the overall performance of the gear.
The production of high-quality gears requires optimal gear and mold design and a precise, repeatable injection molding process.
Numerical simulations were used to investigate the influence of the gate position, the processing technology (compression molding, Variotherm) and the process parameters on the dimensional accuracy of the gears.
To investigate the gating position, process parameters and technology, we performed several numerical simulations of injection molding using Moldflow software on four different gear designs. The various gear designs were developed according to the VDI 2736 standard and the design guidelines for plastic gears.
The simulations show that the number and position of the gates can have a dramatic effect on the gear injection molding process and the dimensional accuracy of the gear.
By analyzing the influence of different gate positions on the deformations, the results show that the position and number of gates on the gear play a key role in ensuring the dimensional accuracy of the gear, especially the runout.
In addition to the position of the gates, the gear design also has an influence on the dimensional accuracy of the gear. An optimized gear design is more homogeneous and has a lower volume shrinkage, which is reflected in lower gear deformations and thus in a lower runout. In addition to the effect on deformations, the optimized gear design has a shorter cooling time compared to the basic design, which is reflected in more economical production.
The results showed that the number and location of the gates play a key role in ensuring the dimensional accuracy of polymer gears. The gear geometry and the process parameters also have an influence on ensuring dimensional accuracy, but the effects are much smaller than the influence of the gate position.

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Noise Evaluation Of S-Polymer Gears

Boštjan Trobentar[1*], Matija Hriberšek[2], Simon Kulovec[2], Srečko Glodež[1], Aleš Belšak[1]
[1)] Smetanova 17, 2000 Maribor, Slovenia
[2)] Podkrižnik d.o.o., Lesarska cesta 10, 3331 Nazarje, Slovenia
[*]bostjan.trobentar@ledinek.com

Polymer gears are widely used in many industries and applications, such as office appliances, service and mechatronic devices, household facilities, computer and laboratory equipment, medical instruments, etc. Some of the main benefits of polymer gears are high specific mechanical properties (high size-weight ratio), good tribological performance (low coefficient of friction, self-lubrication), high resistance to impact loading due to the elasticity of the material, ability to absorb and damp vibration, to reduce noise; polymer gears can also be used in wet environments, food preparation areas, etc. However, polymer gears also have some disadvantages, such as lower load-carrying capacity at higher operating temperatures if compared to metal gears, difficulties to achieve high tolerances (especially in the case of moulded gears), etc. [1, 2].

In the authors' previous work [3, 4], some aspects on the failure modes of polymer gears regarding the VDI 2736 Standard [5] have been investigated where both involute and S-gears were considered. In this study, an acoustic signature of S-polymer gears was investigated and compared to the standardised involute gears. Basic evaluating characteristics included noise during operation, which is of particular significance when noise reduction is expected. The measured signals were analysed in time and frequency domains and the levels of acoustic activity were compared. The experimental results of the noise evaluation showed some advantages of S-polymer gears if compared to the standardised involute polymer gears.

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Thermal Behaviour Of Polymer Spur Gears During Running–A Comprehensive Analysis Using Numerical And Experimental Approaches

B. Černe [a]
[a] *Faculty of Mechanical Engineering, University of Ljubljana, Aškerčeva 6, 1000 Ljubljana, Slovenia*
borut.cerne@lecad.fs.uni-lj.si

The service life of polymer gears is highly correlated with their operational temperature level. The gear's peak temperature rise can analytically be described as a superposition of two components: the nominal (bulk) temperature rise, occurring gradually, over a large number of gear running cycles and the almost instantaneous flash temperature rise, which takes place during the gear meshing cycle and dissipates quickly after meshing completion. The overall temperature rise is dictated by a wide array of parameters ranging from the power transmission system geometry, the materials used, the transmitted torque, running speed, type of lubrication and environmental conditions (temperature, humidity, heat radiation, etc.). The sheer number of influencing parameters makes the numerical modelling and consistent experimental analysis of the polymer gear's temperature rise a very complex task. In our work we focused primarily on developing a numerical model for an accurate spur gear temperature rise evaluation and a suitable experimental procedure for the validation of the model. The presented results are based on a number of previous studies [1-4] which provided the foundations for developing a comprehensive spur gear model that can be employed to analyse a wide range of gear profiles—involutes or non-involutes—along with various gearing system geometries and load conditions. The model could provide an effective upgrade to typically employed gear design procedures and enable a more accurate and reliable evaluation of the polymer gears' expected service life. Combined with typical design methods like the one defined in the VDI 2736 guideline and other recently developed design optimisation procedures [5] it could form the basis for obtaining more efficient power transmission solutions, tailored to the specific system requirements.

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Wear Behaviour Of Coated Polymer Gears

Brigita Polanec[1*], Frančišek Tašner[1], Srečko Glodež[1]
[1] *Smetanova 17, 2000 Maribor, Slovenia*
[*] *brigita.polanec@um.si*

As presented by Kalin et al [1], the main advantages of polymer gears over metal ones are the ease production with low manufacturing costs, good noise-damping properties, good tribological properties without lubrication, as well as chemical inertness. However, polymer gears have some disadvantages compared to metal gears, e.g. inferior mechanical properties, worse thermal conductivity and thermal resistance, and worse manufacturing tolerances. Because gears are key elements of many mechanical systems to transmit power and rotational movement, their eventual failure can cause the deadlock of the whole system. Thus, the proper estimation of load capacity against failures under given loading conditions is crucial when dimensioning the gear drives. In the case of polymer gears, the standardised procedure according to VDI 2736 [2] is usually used for that purpose. This standard includes details of calculating load-carrying capacity of polymer gears in regard to the following failure modes: melting, tooth root fracture, toot flank fracture, pitting, toot wear and tooth deflection (in this paper, only the wear behaviour of polymer gears is addressed). Because polymer gears are usually running without lubrication, the high contact friction and consequently high degree of wear may be the main reason for the short fatigue life of gear drive, especially in medium to high power transmission applications. As reported by Petrov et al [3] and Bae et al [4], the wear resistance of polymer gears may be increased when some kinds of surface coatings are applied on the analysed polymer gears.

In this study, a comprehensive experimental investigation of the wear behaviour of coated spur polymer gears made of POM was performed. The coatings investigated were aluminium (Al), chromium (Cr), and chromium nitrite (CrN). Al was deposited in three process steps: by plasma activation, metallization of Al by the magnetron sputtering process, and by plasma polymerization. Cr deposition was performed in only one step, namely the metallization of Cr by the magnetron sputtering process. The deposition of CrN was carried out in two steps. The first involved the metallization of Cr by the magnetron sputtering process while the second step, vapor deposition, involved the reactive metallization of Cr with nitrogen, also by the magnetron sputtering process.

The experimental results were shown that the influence of metallization with aluminium, chromium, and chromium nitrite surface coatings on the wear behaviour of analysed polymer gear is not significant. From that respect, a new testing using thicker coatings will be investigating in the further research work.

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Influence Of Rotational Speed On The Gear Mesh Stiffness Of A Polymer-Metallic Spur Gear System

Ala Eddin Chakroun[1], Ahmed Hammami[1], Ana De-Juan[2], Fakher Chaari[1], Alfonso Fernandez[2], Fernando Viadero[2], Mohamed Haddar[1]
[1] *Laboratory of Mechanics, Modeling and Production (LA2MP), National School of Engineers of Sfax, BP1173 –3038 –Sfax –Tunisia*
[2] *Department of Structural and Mechanical Engineering, Faculty of Industrial and Telecommunications Engineering, University of Cantabria, Avda de los Castros s/n 39005 – Santander - Spain*
Chakroun.ala.eddin@gmail.com

Over the years, polymer gears are becoming more and more reliable in various fields and applications. It is therefore interesting to study their dynamic behavior. One of the main factors in the dynamic response is the gear mesh stiffness. It has been widely studied in metallic gear applications while it is not frequently mentioned in polymer gears ones. Polymers have a viscoelastic behavior. Thus, each tooth will experience two different periods of behavior. The first period starts from the engagement of a tooth and ends when the tooth is completely disengaged. In this period the behavior is called creep. The second period is longer than the first. It is the period during which no load is applied to the tooth. In this period the behavior is called recovery. The longer the recovery period, the closer the tooth gets to its original shape. It is therefore important to study any parameters that influence this period. The rotation speed has a direct impact on the length of this period. In this study, the impact of rotational speed on the gear stiffness of a polymer-metal spur gear system is investigated. Generalized Maxwell Model (GMM) is used to model properly the viscoelastic behavior of polymer. This model consists of parallel Maxwell cells, a Maxwell cell is a combination of a spring and a dashpot connected in series. Pole-Zero Formulation (PZF) is applied to identify the parameters of this rheological model. Steel and nylon 6,6 are chosen as gear materials. All deformations are considered to occur on the polymer gear due to the huge difference in Young's modulus of the two materials. The stress applied on the teeth is deduced from the sharing factor introduced in the literature. Eventually, the mean value of the gear mesh stiffness of the proposed gear pair is determined for deferent turning speeds

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The Tribology And Surface Thermal Behavior Of Tooth Flank Of Non-Metallic Gear: The Case Of Dry Running

Khalid Abdulkhaliq M. Alharbi
Mechanical Engineering Department,Umm Al-Qura University,
Makkah, Saudi Arabia
kamharbi@uqu.edu.sa

This piece of work represents the valuable results of the extensive investigations on some specified polymer gears to report the variance of mechanical performance. The results of the experimental work of running certain material gears at different applied loads and variant speeds to record the gear tooth wear rate and thermal contact behavior have been presented. Nylon, acetal and polycarbonate (PC) materials were chosen for the initial set of tests. As common, injection molding and machine-cut manufacturing techniques were used to build the test gear samples. Wear, endurance and surface temperature were simultaneously and continually recorded using the specified test rig. Findings were contrasted with the literature and validated with the theory of polymer wear and fatigue. The initial testing series leads to more specified testing with certain parameters to investigate and analyze the tooth flank tribology and thermal behavior.

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Specialty Polymers for High Performance Gears

S. Montani[1], R. Patricio[2]
Solvay Specialty Polymers Italy, Viale Lombardia 20 Bollate (MI) 20021, Italy
Stefano.Montani@solvay.com

The transportation sector is under tremendous pressure due an ever-growing population and limited global resources. Efficiency targets & regulations are driving rapid adoption of downsized engines.
At the same time, the increased electrification of the powertrain is demanding new solutions to improve noise, vibration & harshness during electric operation. Moreover, new concepts for braking systems and hybridization are demanding improved actuation technology.
Leveraging on its broad product portfolio, which features friction and wear modified - as well as unfilled polymers, Solvay Specialty Polymers is in the position to provide high performance plastic solutions for the most challenging gear applications.
Solvay sets the foundation for an optimal material selection in the generation of gear specific data by means of single tooth bending and 4-square testing combined with technical expertise on gears, which permit to address the application's requirements to the most adequate solution.
Further, Solvay targets to go beyond being only a raw material supplier and become a trusted partner who can drive projects along the full value chain, from raw materials to design, from prototyping and testing to serial production.
Beyond innovation, sustainable progress is also part of Solvay's DNA. Concrete actions have been taken over the years by developing new products using bio-based raw materials and recycled content.

Use of plastic gears in hydraulic pumps

Michał Banaś[1], Jarosław Stryczek[1], Sławomir Bednarczyk[1], Krzysztof Biernacki[1]
Wrocław University of Science and Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław
michal.banas@pwr.edu.pl

Various uses of plastics in mechanical engineering are fostering the search for new areas where plastics can improve the properties of existing equipment. One such area is hydraulic drives [1], in which the use of plastics is becoming more and more widespread.
In many hydraulic elements, the proportion of plastics is increased, eg in valves [2], cylinders [3]. This group also includes hydraulic pumps in which the gears are made of polymers.
The appropriate selection of the materials of the gears and pump bodies means that apart from typical hydraulic fluids, such as mineral oils, other liquids, e.g. water, can also be used.
The technology used [4] allows obtaining pressure values up to 5 MPa with oil and up to 2 MPa with water [5]. Such values of the working pressure allow the use of pumps with plastic wheels in medium pressure auxiliary systems and in systems with aggressive working fluids.
The paper presents selected results of research, theoretical and experimental works involving gerotor gears used in hydraulic pumps.

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