Comparative study regarding the wear of gearwheels manufactured through additive technologies

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Abstract. The article presents the results of the experimental research on the wear of gearwheels manufactured by an additive technology. It was realized eight gearwheels with the same module and number of teeth by means fused deposition modelling technology from different materials, including PLA, ABS, CarbonFil, nylon. In order to determine the teeth wear, pitting, thinning of teeth at the base in a gear that requires a continuous and constant operation, a demonstration set-up was designed and realized to highlight the mechanical loads of the eight gearwheels made by additive technologies.

1 Introduction

Elements for transmitting, transforming, and amplifying signals generally have the role of transmitting and transforming the motion, either quantitatively (from one speed to another) or qualitatively (from rotation to translation or vice versa). Transmission and transformation of the rotation motion, the most widespread of the technique, can be done with friction wheels, gears, transmissions through belts and chains.

In practice, it is often required that the speed of the driven element be kept constant at a constant speed of the leading element. To achieve this goal, it is necessary that the friction or toothed wheels, in the direct contact transmission, have the circular section.

The direct transmission of the rotation motion with the constant transmission ratio and in the case of large forces can be achieved by circular section gearwheels. Transmissions through gearwheels, known for many centuries, from antiquity, have been continuously studied and perfected, reaching today a general theory of gears. It is now possible to realize gearwheels of a rigorous construction and of great durability.

The main materials used in fabrication of these elements are steel, cast iron, some non-ferrous metals and plastics.

Starting from the plastic materials used in the last period of time on the wider scale for different categories of gears presents a series of qualities: partially amortizes vibrations and reduces noise; due to the low Young's modulus, it elastically compensates the tooth errors

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being limited in use over certain limit temperatures (80°C in the case of polyamides). [1-3]. There are some representative studies of gearwheels realized by additive technologies. Among these, Farstad et al. [4] investigate the friction of thermoplastic gearwheels. Vasilescu and Fleser [5] develop a research about the influence of some technological parameters on 3D printed gears.

The authors of the article present a comparative study of the wear and contact pressure of gearwheels realized by additive technologies from different materials: PLA, ABS, PETG reinforced with carbon, nylon, keeping the module and the number of teeth constant [1-3].

2 Control methods

Starting from the experimental research on gearwheels obtained by additive technologies on a Frenco ZWP 06 [6] inspection stand, the authors want to develop a comparative study of these elements having the same geometric parameters, but differing in their construction materials.

The Frenco ZWP 06 is specially designed for small samples (machined parts) and is very suitable for plastic gears. The measuring force can be reduced to 0 N. The sophisticated design is extremely precise and sensitive, because it is necessary to measure small specimens. The measurement sequence is driven by the engine in default mode. The double flank gear test is a quick and simple inspection method for gears. The basic principle of the double flank gear test is based on a master gear (a near perfect gear) and a workpiece in rolling contact, free from backlash. The inspection machine has one rotational axis which is fixed and one which is movable. The centre distance variations during the rolling process are caused by form errors on the workpiece and are the basis for the quality assessment.

Fig. 1. The inspection of gearwheel on Frenco ZWP 06

This stand aims to verify the geometric parameters of the gears, the deviation of the distance between the axles in the class 4 of precision.

The software creates a clearly laid out record showing (the principle is presented in the Fig.2):

Fig. 2. Representing deviations F_i'' , f_i'' , F_r''

Double flank rolling deviation F_i'' is the difference between the maximum and minimum values of the working centre distance, a'' , which occurs during a radial (double flank) composite test, when the product gear with its right and left flank simultaneously in tight mesh contact with those of a master gear, is rotated through one complete revolution. (DIN3960/3963) Double flank rolling tooth to tooth deviation f_i'' is the value of the tooth radial composite deviation corresponding to one pitch, $360^\circ/z$, during one complete cycle of engagement of all the product gear teeth (z = number of gear teeth). Radial Runout F_r'' represents the value of radial runout of the gear between the maximum and the minimum radial distance from the gear axis as observed by removing the short-term or undulation pitch deviations and analyzing the long-term sinusoidal waveform.

Fig. 3. Results of inspection of 3D printed gearwheel

3 Experimental

The experimental researches aim to highlight the possibility (viability) of the temporary use of the gearwheels fabricated by additive technologies (FDM – Fused Deposition Modelling method), both in terms of the precision of the execution (tooth profile, tooth leg, tooth surface condition), as well as the advantage of realizing of these elements in a short time with low cost, if in different industrial equipment requiring an uninterrupted cycle of operation (food industry, petroleum industry) a gearwheel is worn and the replacement, repair, reconditioning or execution of the gears by conventional cutting methods (copying method, running method) takes a long time and can block the production process.

For this purpose, a set of 8 gearwheels with the same geometric parameters from different thermoplastic materials were designed and manufactured by additive technologies (Fused

deposition modeling): 3 of acrylonitrile butadiene styrene (ABS), 3 of polylactic acid (PLA), 1 of polyethylene terephthalate glycol-modified (PETG) reinforced with carbon fiber and 1 of nylon. ABS and PLA are the most common materials for this technology with quite good mechanical properties. Nylon has a very high chemical resistance, making it suitable for many industrial applications, but at the same time it has hygroscopic properties. Among the advantages of PETG are lightweight and dimensional stability. However, the composition of carbon fiber from this material can damage the extruder by its abrasion and toughness. Before the testing of the gearwheels on the experimental stand, they were investigated using the Bresser Biolux NV 40x microscope (tooth profile and bottom land).

Fig. 4. Microscopic investigations of 3D printed gearwheels

The experimental stand designed and realized by the authors aims to check the wear of the gearwheels (the tooth profile, the bottom land, the state of the gear surfaces) obtained by additive technologies [7-9]. The stand is 1:1 using a JGA 25-370 - 6V gearmotor with 58 rpm as the power source, the drive wheel is made using FDM (Fused Deposition Modelling) technology and the OLC 50 driven wheel. The durable moment is given by a propeller that is immersed in a working fluid. Each gearwheel was tested for 3 hours in a clockwise direction and 3 hours in the anti-clockwise direction.

Table 1. Dimensional comparison of 3D printed gearwheels

Material	Nominal dimension		Diameter [mm]	Thickness [mm]
	Diameter [mm]	Thickness [mm]		
PLA red	58	4	57.57	4.09
PLA orange	58	4	57.29	4.18
PLA yellow	58	4	57.5	4.37
ABS grey	58	4	56.77	4.58
ABS gold	58	4	57.49	4.32
ABS green	58	4	57.35	4.35
PETG	58	4	57.55	4.45
Nylon	58	4	56.33	4.60

Fig. 5. Testing of gearwheels realized by additive technologies

Research has shown that after testing of the toothed wheels, the tooth profile does not appear to be affected by any material used in the study. In contrast, the condition of the surfaces and the bottom of the tooth shows signs of wear during operation (Fig.7 and Fig.8).

Fig. 6. Comparison of tooth profile before and after testing

Fig. 7. Comparison of bottom land before and after testing: a – PETG reinforced with carbon; b – ABS gold; c – PLA yellow; d – PLA red

Fig. 8. Comparison of bottom land before and after testing: a – ABS grey; b – ABS gold; c – PLA orange; d – Nylon

The experimental results obtained for the 8 gearwheels (tooth profile, bottom land and surface condition) are presented in Figure 6-8 (before and after testing). The roughness of the obtained pieces was between 2.95 – 3.89 μm with the mean of 3.42 μm . In terms of dimensional accuracy, PLA gearwheels have the best results with the smallest deviations

from the nominal dimensions (Table 1). The biggest deviations belong to the nylon printed parts. It can be observed from the images that the most unaffected material is PLA, and the ABS elements give the most significant wear traces after testing. Also, the surface of PETG and nylon gears is noticeably changed after testing.

4 Conclusions

The advantages of FDM (Fused Deposition Modelling) systems result from the fact that the manufacturing process does not produce material in the form of waste, it uses cost-effective materials and FDM (Fused Deposition Modelling) systems are easy to use and do not require special conditions for installation and operation, direct production in small series of functional parts with features and characteristics specific to traditional technologies.

In this paper, the authors designed and made 8 gears with the same geometric characteristics and 4 different thermoplastic materials using FDM (Fused Deposition Modelling) technology. These elements were later tested on an experimental set-up designed by the authors in a continuous operating cycle in order to evaluate their wear. PLA wheels have been proven to be the most performing in terms of wear, which can be most viable as intermediate gears in production cycles. Despite the better mechanical properties of printed ABS parts, they are more significantly worn after a continuous use cycle than the PLA parts. Also, PETG and nylon realized elements give clear signs of wear after testing.

This study highlights the possibility of using gears realized through additive technologies. These new manufacturing methods can be an inexpensive and fast solution for temporary replacement of defective items. Additionally, additive manufactured gearwheels with suitable mechanical properties can be used in various industries where similar metallic parts should be avoided.

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