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Original Research Article

Wearout evaluation of mechanic parts with multimaterial 3D printing

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Abstract: Evaluating the reliability of a part is of great importance when developing components and devices in medical engineering. In order to examine the wear on the surface of mechanical components, a thin top layer of the part is 3D printed in a different color of the same material. Thus, after performing a wear out test with the component, the mechanical wear can be visually inspected.

I. Introduction

Many applications in medical engineering have high requirements to the reliability of mechanical components. In order to evaluate the reliability of mechanical components, various testing methods have been established. The long list goes from in-silico simulations via destructive testing for the analysis of deformation and breakage to non-destructive testing by means of optical methods [1], terahertz imaging [2], x-ray imaging or computed tomography [3] among many others. These technologies examine the volume of a part with its mechanical properties as well as possible defects within the component. In order to inspect the wear dynamics on the surface, coatings, like for example a paint can be applied to the components in order to see which parts of the surface are subjected to the highest wear and to see if this abrasive wear is equally distributed throughout the functional parts of the surface. This method is also described in DIN3990-1. The disadvantage of this method is that the layer of paint may have different mechanical and tribological properties than the original part-material. Our approach makes use of the capabilities of multi-material 3D printing, by manufacturing a very thin top-layer of the part from the same material as the rest of the part, but in a different color. This way, the mechanical and tribological properties of the part are not affected, but a visual inspection of the part after a test run reveals the distribution of surface-wearout on the component very clearly.

II. Material and methods

A pair of spur-toothed involute bevel gears with a modul of $m = 6$ mm and a tooth number of 37 and 17 for gear and pinion respectively has been designed in Solidworks (Dassault Systemes, Vélizy-Villacoublay, France). This results in a pitch diameter of $d_e^{\text{gear}} = 222$ mm and $d_e^{\text{pinion}} = 102$ mm. For the initial test procedure both bevel gears have been scaled by a factor of 0.4.

The gearwheels were prepared for printing with GrabCAD Print (Stratasys, Eden Prairie, USA) and printed on an J850 PolyJet 3D printer (Stratasys, Eden Prairie, USA) with VeroPureWhite and VeroBlack Plus in high-mix mode (layer thickness 27 µm).

According to the datasheet, both materials have equal mechanical properties (tensile strength between 50 MPa and 65 MPa, with Shore hardness between 83D and 86D). Both parts consist of a core and a 0.3 mm thick coating, using the cover of one as the core material of the other. Figure 1 shows the pair of gear wheels after the test run.

After support removal, the gearwheels were installed in a test stand and run at different speeds below 300 rpm with a mean revolution on the driven gear of 232 rpm for approximately 20 hours. Afterwards, the wheels were removed from the test stand for visual inspection

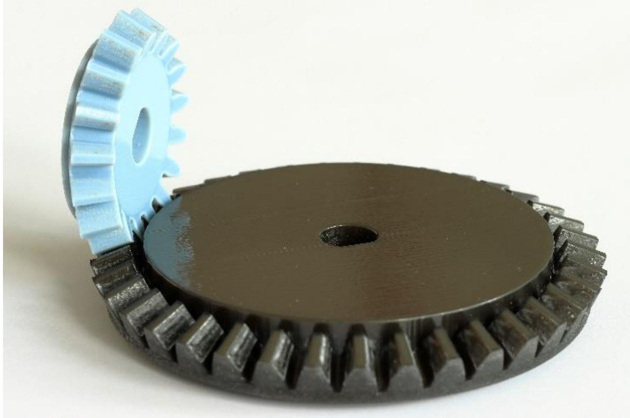

Figure 1: 3D printed pair of gearwheels. The pinion is black with a white surface, the gear is white with a black surface.

III. Results and discussion

After the test run, there were wearout marks visible on both, the pinion and the gear. There is no damage to the teeth of either wheels and the mounting holes for the driveshafts are undamaged. A closer look at the contact pattern [4] on the gear reveals a tip contact, where the upper part of the teeth shows an evenly distributed wearout across the radius in drive direction (see Figure 2).

Figure 2: The contact pattern on the gear in drive direction shows an evenly distributed wearout along the upper half of the teeth.

The other side of the teeth, which bears a load in drag direction does show a wedge type center contact pattern, tapering to the tip. As depicted in Figure 3, the inner part of the teeth towards smaller radii shows v-shaped wear marks. This may indicate a slight misalignment of the driveshafts under braking.

On the pinion, wearout was less distinct. On the drive side of the teeth there is light rub-on of material from the gear with an inclined contact (see Figure 4) which can be seen on some of these teeth, possibly due to heating effects at the high speeds of the driving wheel.

Figure 3: Contact pattern on the gear in drag direction shows a concentration of wearout along the upper half of the teeth only towards the smaller radii.

Figure 4: Wearout marks on the pinion in drive direction show only light rub-on of material from the gear, but no signs of abrasion.

On the drag side of the pinion teeth, there is no significant wearout visible (see Figure 5).

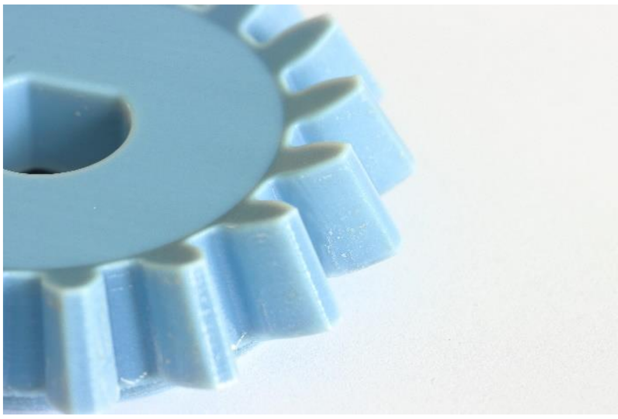

Figure 5: There are no significant wearout marks on the pinion in drag direction visible.

IV. Conclusions

After visual inspection of the two-color bevel gear pair, we conclude that the method of applying a thin surface layer on 3D printed gear wheels can reveal insights into the wearout dynamics of mechanically stressed components. The method is applicable in those cases, where multi-material printing is possible, such that different material colors can be used during the manufacturing of a part.

Due to the lower spatial resolution, we do not consider the method applicable in standard FDM processes even though dual extrusion printers would allow for the two-color approach as well. Depending on the application, the thickness of the surface layer can be varied. Additionally, introducing multiple layers of different color can be used to quantify the wearout in more detail.

We see the described method primarily as a tool for the development of mechanical assemblies, which allows for the experimental verification of the contact force distribution. However, in some cases, it could also be beneficial to use the approach not just during development of mechanical assemblies, but also in a production environment.

This way, a color change of components which are usually not subject to higher friction could clearly indicate a malfunction in one of the other components to the service personnel.

As multi-material 3D printing offers a high degree of topological freedom, in special cases, the idea can be even pushed further by not just using homogeneous layers, but also more complex patterns or even the implementation of numerical values, pictograms or text.

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Author's statement

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study.

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