Extensive material characterization for series production of 3D printer components

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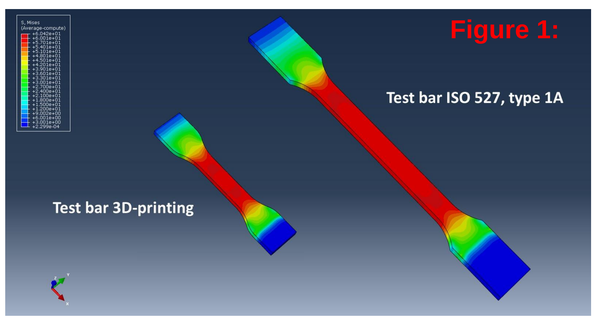
Introduction

In the last decade, 3d printing technology has undergone rapid development. From the original technology for the production of prototypes or special applications in medicine, racing or aerospace, to individual production and economically competitive series production. Additive manufacturing opens up a variety of possibilities to manufacture even geometrically complex components from metallic, ceramic or polymeric materials [1].

The joint research project “Material and process optimization for series production of 3D printer components” aims to develop fundamentals for optimizing 3d printed polymeric components. Since components from 3d printing behave significantly differently than, for example, injection moulded parts, they also have to be designed and dimensioned differently. The differences can be found also in the material properties and in the processing-related material structure and surface morphology.

Instrumentation and experiments

Hence there is the necessity to characterize the resulting mechanical, morphological and chemical properties and the ageing behaviour of the versatile polymers (e.g. ABS, PA, PC, PLA, PP, TPU, or fibre reinforced plastics) used for the different 3d printing processes (Fused-Deposition-Modelling (FDM) or Fused Filament Fabrication (FFF), Stereolitographic techniques (SLA), Selective Laser Sintering (SLS), …) under different printing parameters. Therefor a special test specimen was designed (Figure 1).



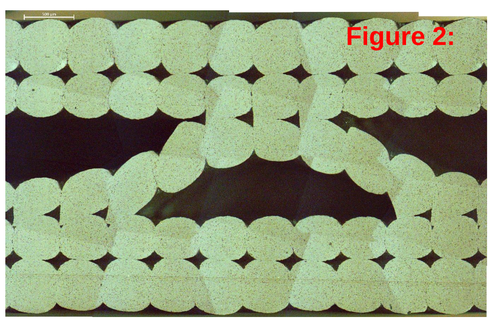


Figure 1: To improve the results of all mechanic analysis (static, dynamic, creep and fatigue), a separate test specimen was dimensioned especially for 3D printing parts. Small parts with the largest possible sample cross-section must provide comparable results to standard specimens, like test bar ISO 527, type 1A.
Figure 2: Stitched Light Microscopy image of a cross section of a FDM printed sample out from the supporting structure made of PLA.

For the dimensioning of printed components, a detailed description of the material properties under application conditions must be provided. This requires knowledge of the material strength and the reduction of strength under mechanical stress. For a general description of this behavior, reduction factors have been determined to define the nominal design stress according to the given load cases, e.g. static or dynamic mechanical loads, notching effects, elevated operation temperature or aging / exposure.

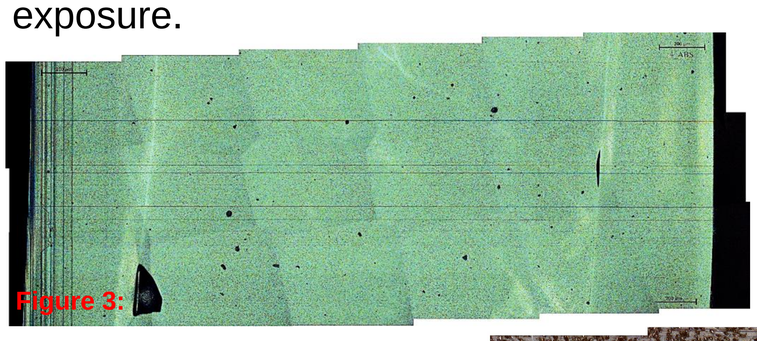
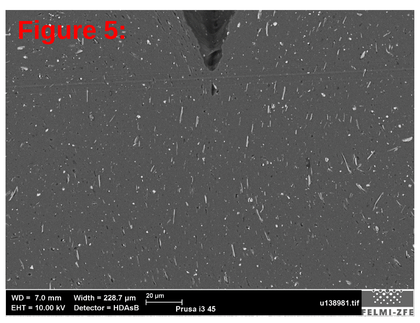
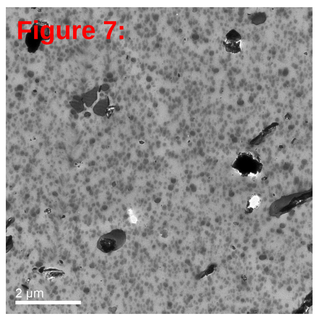


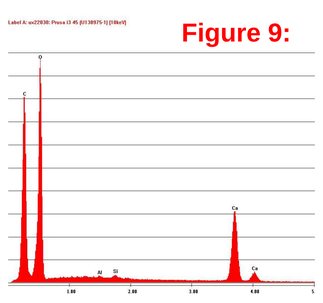
Figure 3: Stitched Light Microscopy image of a cross section of a FDM printed sample made of ABS.

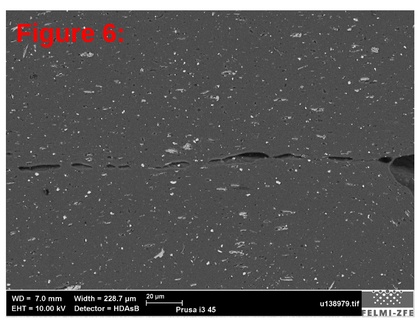
Figure 4: Stitched Light Microscopy image of a cross section of a FDM printed sample made of PA6 CF - the different fiber orientations are clearly visible.

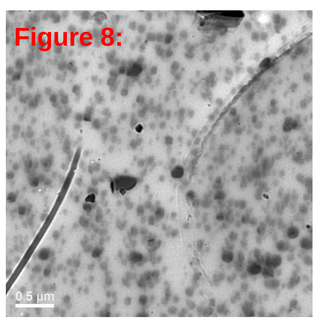
Surface morphology is monitored with large area and detailed Environmental Scanning Electron Microscopy (ESEM). Atomic Force Microscopy (AFM) can connect the surface structure with local mechanical properties. Computed tomography (CT) enables an insight into the component (defects and cavities). For a local detailed structure analysis the samples are cross-sectioned with microtomy techniques and then characterized with a multiscale approach of different microscopic methods. From stitched Light Microscopy (LM) images in the mm range (Figures 2, 3, 4), via Scanning Electron Microscopy in the µm range (Figures 5, 6), up to interfaces and fillers distribution investigated with Transmissions Electron Microscopy (TEM) in the nm range (Figures 7, 8). Raman Imaging and Scanning Electron Microscopy (RISE) provides correlative elemental and chemical information by combining EDS (Figures 9, 10) and Raman spectroscopy (fibre reinforcement, distribution of additives, fillers and pigments) [2, 3].

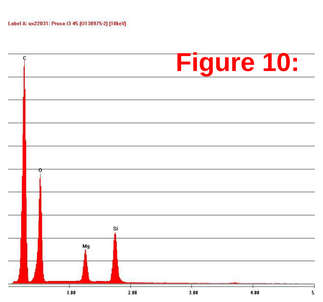












Figures 5 and 6: The (E)SEM BSE images of the cross sections of a FDM printed sample made of PLA show the distribution of the fillers and the more or less merged interfaces.
Figures 7 and 8: The TEM BF images of the ultra thin sections of a FDM printed sample made of PLA show the distribution of the fillers and pigments.
Figure 9: The EDS spectrum shows the rather blocky and partly agglomerated calcium carbonate fillers from the REM and TEM images.
Figure 10: The EDS spectrum shows the platelet-shaped talcum fillers with their needle-shaped appearance from the SEM and TEM images.

References/ Literature

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