AFM-Imaging of sectioned 3D-printed Polymer-Polymer Interfaces

D. Schmiedjell[1*], C. Angerer[1], D. Schäffl[1], S. Hild[1]
[1]*Institute of Polymer Science (Johannes Kepler University), Linz, Austria*
[*]*david.schmiedjell@jku.at*

Additive Manufacturing (AM) has rapidly become a prominent technology for applications ranging from high-end uses like aerospace engineering and medicine, to consumer products. One of the most widely used AM techniques is Fused Deposition Modeling (FDM). In FDM thermoplastics are molten and deposited on top of each other in layers. This enables the user to create layer-composite materials allowing optimization of properties such as stiffness and flexibility. [1, 2] However, a major challenge for products created with FDM is the failure of adhesion between print-layers, causing delamination. Adhesion between polymer layers has been described using various mechanisms: physical or chemical bonding, as well as interdiffusion, which is generally considered the most important mechanism [3]. Interdiffusion occurs when two molten polymers are brought into contact. After the initial wetting, mobile polymer chains can move across the interface, creating an interdiffusion region at the polymer interface, which greatly influences the strength of the layer-layer bond [3, 4]. The resulting layer adhesion has been studied extensively on a macroscopic scale, focusing on tensile and bending tests. However, very little research has been done to characterize the layer-layer interface at the microscopic level. Atomic Force Microscopy (AFM) is a microscopy technique based on the interactions between a fine probe tip and the sample surface. It can detect changes in material properties at a nanoscopic resolution. Thus, variation in the composition of the interdiffusion layer can be analyzed due to changes in chemical or mechanical applying the respective AFM techniques, such as phase imaging or contact stiffness.

This study uses AFM techniques to investigate the nature of the contact-region between adjacent layers in layer composites consisting of commonly 3D printed thermoplastics, such as PETG, TPU, and ABS. In order to maximize contact area and optimize conditions for interdiffusion, the polymers were printed on top of each other in parallel lines at elevated bed temperatures. The printed TPU/ABS and TPU/PETG samples were subsequently sectioned using a microtome until a sufficiently smooth surface, perpendicular to the interface, was exposed. The remaining cutting artifacts on the surface were usually well below 100 nm deep.

At first, the polished surfaces are analyzed with regard to topography using the intermittent contact technique. Simultaneous phase imaging can provide the first indications of the formation of an internal diffusion layer. Material sensitive techniques such as friction, stiffness, and adhesion force imaging showed an abrupt change of these properties at the interface, instead of an expected gradual shift from one bulk material to the other. As such it can be said that no significant interdiffusion region could be found in the analyzed samples, suggesting other adhesion mechanisms are dominant in multi-material FDM. Future experiments will investigate the effects of post-print annealing as well as compare results with other techniques such as confocal Raman microscopy.

Keywords: Additive Manufacturing, Atomic Force Microscopy, Material Testing, Composite Materials

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