FH SCHMALKALDEN
UNIVERSITY OF APPLIED SCIENCES

Fused Deposition Modeling (FDM) Parts - Fracture Analysis

Analysis of the Fracture Mechanisms of Unidirectional Tensile Specimens

Alexander Kißling, Frank Beneke

Background

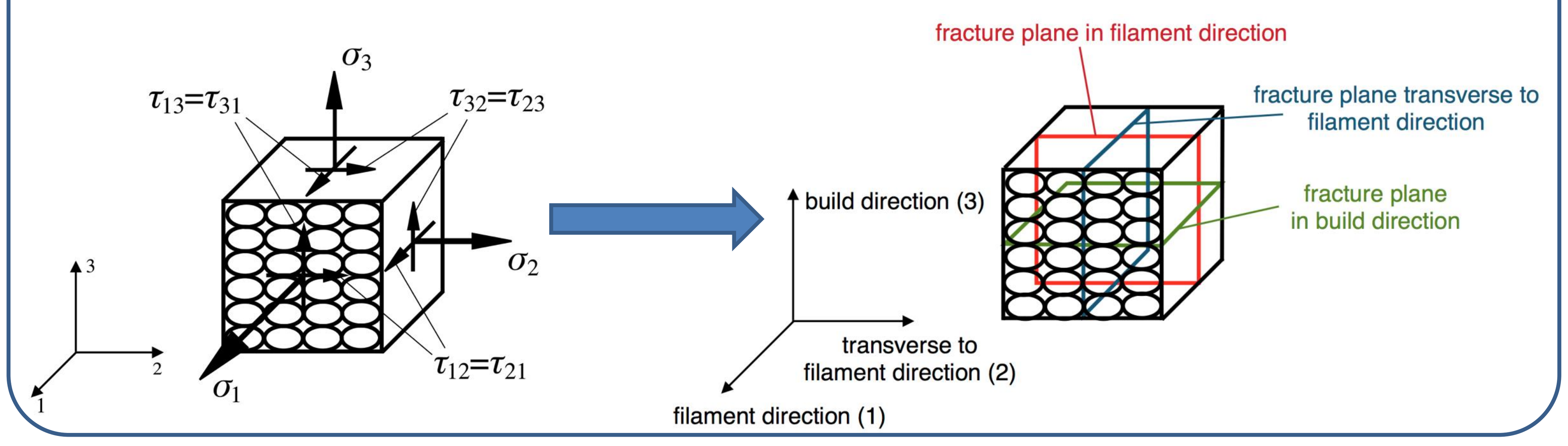
Generative processes such as represented for example by the Fused Deposition Modeling, are a group of production methods, which at first predominantly served the production of representative samples and functional prototypes. In the meantime the actual added value of these technologies goes far beyond these initial applications. The development clearly shows, that generative processes for the manufacture of end products can represent an additional production option. The precondition is, that the specific properties of the material are known and can be used for a calculated design process.

The potential for a use of this production technology for the manufacture of stressed end products in mini- or low volume production lies in the individualization of the product. It is thereby advantageous, that the levels of design freedom are subject to virtually no production-technical restrictions. A particular advantage of this technology is the possible adaptation of the component to the load, not only through its external geometry (as is the case with isotropic materials), but also through the manipulation of the inner mesoscopic-structural construction. A design according to the guiding principle “form follows function” can in this case also be applied in the interior of a structure, through which a load path compatible construction is given a completely new meaning. Essentially this system approach is equivalent to the design of anisotropic composite materials, such as e.g. the optimal alignment of fibers to the adjacent load. This additional adaptation option is enabled through the production characteristics of the FDM process, during which molten plastic filaments are placed alongside each other in a defined direction through an extruder and built up layer for layer. This characteristic produces a specific microscopic structure, from which essentially results an anisotropic material behavior both with regard to the rigidity as well as the strength.

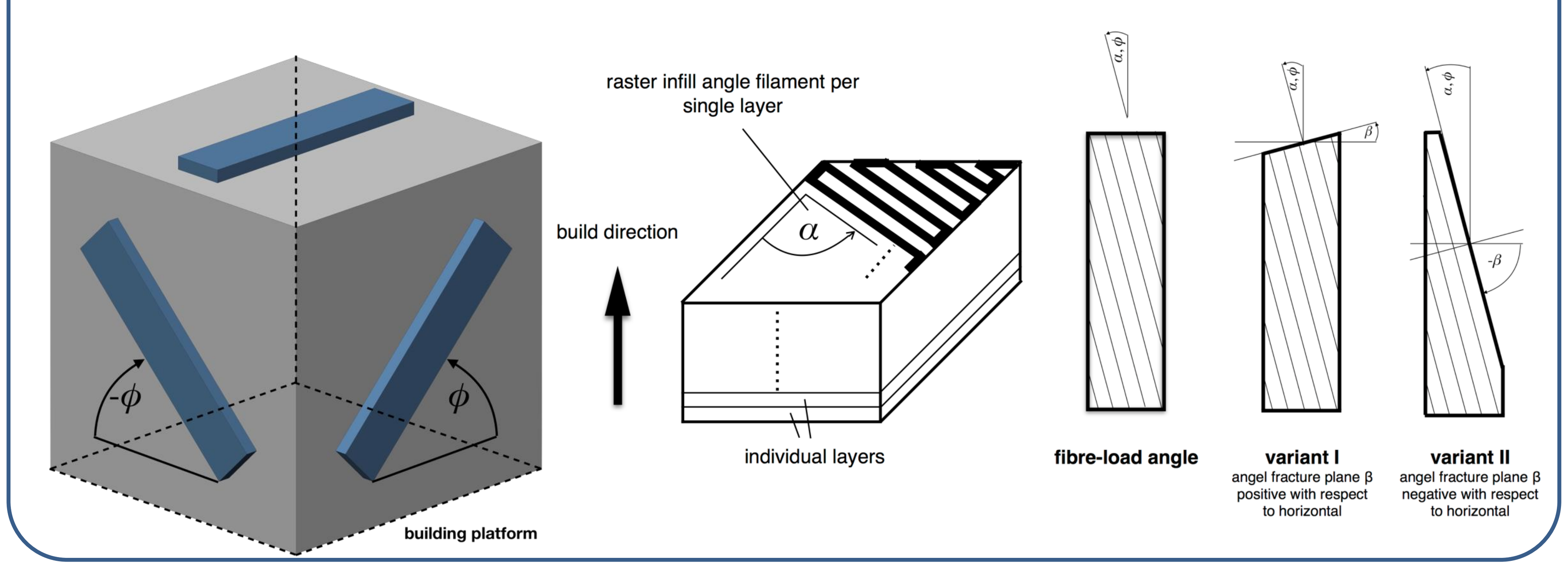
The aim of the research work is to make use of these direction-dependent material properties. As a result a complex structural component can be adapted specifically to the load or designed arithmetically. Consequently a specific failure can be initiated at a defined place or even specifically prevented. Imaginable in this context are for example structural safety elements to protect important components. However, in contrast to this it is also possible to design a supporting structure load path compatible in the sense of lightweight construction principles, so that it just does not fail at a critical point, when the underlying mechanisms are known.

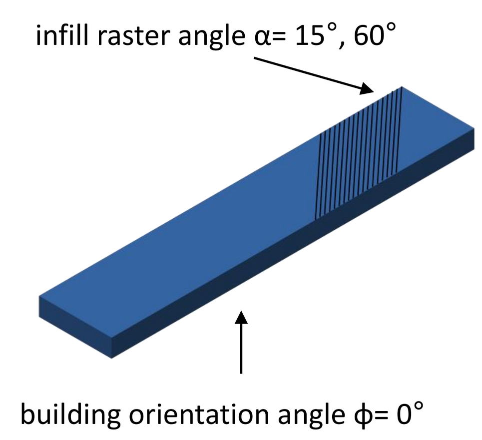
Methodology and Results

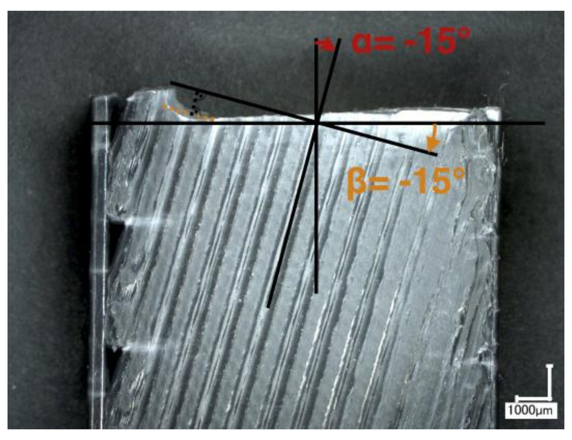
- the production characteristic of the FDM process produces a specific microscopic structure of a unidirectional tensile specimen
- it is assumed, that depending on the interaction, the components in a spatial stress condition can only produce fracture planes, which correspond to the effective planes of the components, resulting in three specific fracture planes



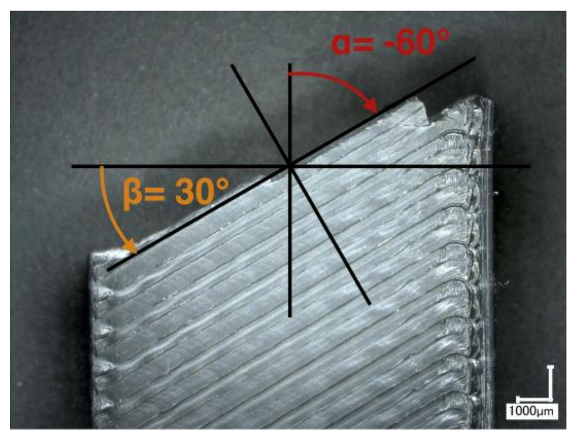
- these stress components or interactions are generated by Off-Axis tensile specimens, that are produced with different orientations in the building space and with different orientations of the individual layers within the specimen
- through the analysis of the fracture angle β it can be determined, up to which degree the stress components have an influence on the respective fracturing and from when a change of the fracture plane is registered



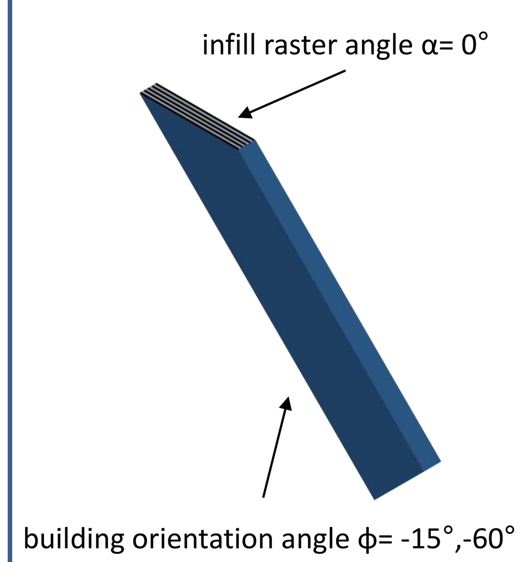


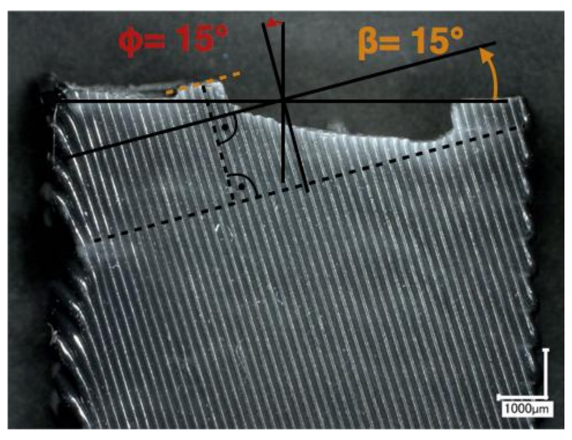


Initial failure at a point in the filament direction due to high σ_1-content → macroscopic inclination of the fracture plane from 0°, probably caused by stress redistribution after the initial fracture

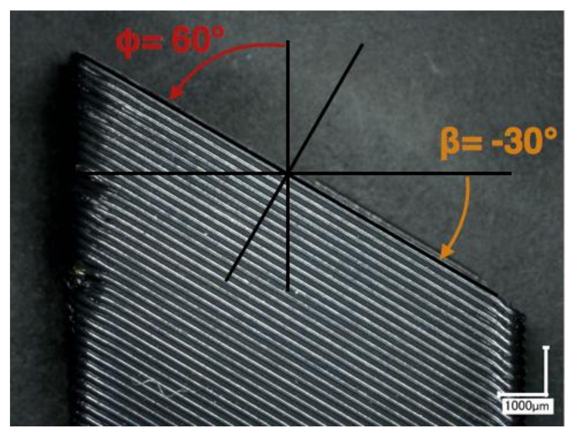


Failure between filaments transverse to the fiber direction due to high percentage of σ_2 and τ_{21} stress interaction in the fracture plane

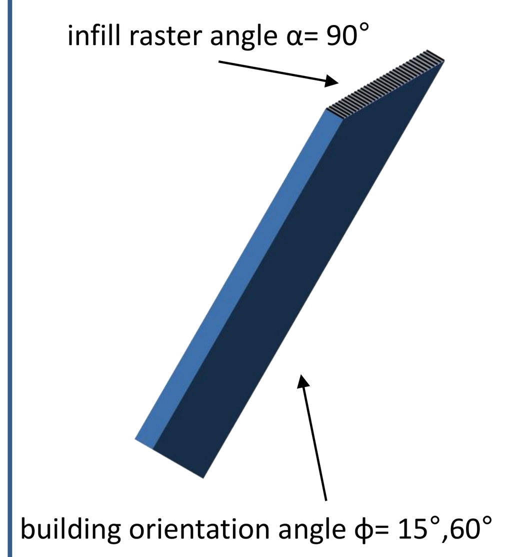


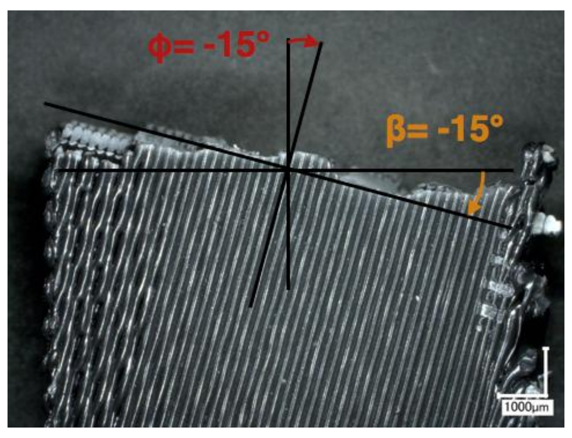


Initial failure in filament direction due to high σ_1-content → deviating angle of the fracture plane, probably due to stress redistribution after the initial failure

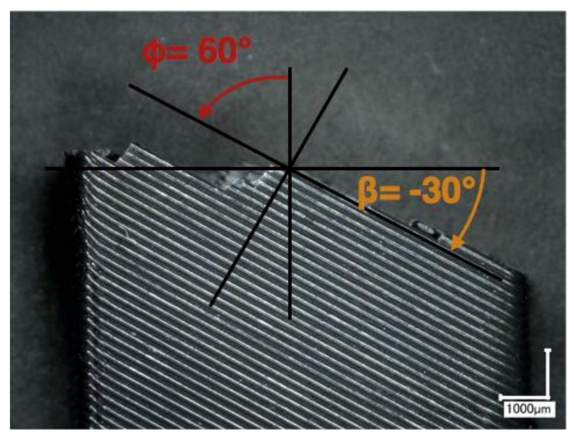


Failure between filaments in build direction due to high percentage of σ_3 and τ_{31} stress interaction in the fracture plane





Failure between filaments transverse to the filament direction due to high percentage of σ_2 and τ_{23} stress interaction in the fracture plane



Failure between filaments in build direction due to high percentage of σ_3 and τ_{23} stress interaction in the fracture plane

Outlook

The evaluation of the first test specimens clearly shows the expected fracture behavior and the existence of the three presumed fracture planes, when it concerns the initial failure. To be able to use this behavior for a target-oriented and optimal arithmetical design of complex FDM-structure components, based on this individual strength hypotheses will be reviewed with regard to their applicability, in order to be able to estimate as precise a prediction as possible of initial damage and its consequences for the entire component.

Author:
Alexander Kißling M.Eng.

Co-Author:
Prof. Dr.-Ing. **Frank Beneke**

Research Facility:
FH Schmalkalden
Fakultät Maschinenbau
Forschungsgruppe Flexible Fertigungstechnologien
Blechhammer
98574 Schmalkalden

Tel.: +49(0)3683 688 2219
E-Mail: a.kissling@fh-sm.de
Web: www.fh-schmalkalden.de

Sponsored by:
ESF EUROPA FÜR THÜRINGEN EUROPÄISCHER SOZIALFONDS
THÜRINGER ZENTRUM FÜR MASCHINENBAU