Abstract „HiPlast“

Starting situation
Adaptive folded plates are gaining increasing interest as filigree, material-saving and convertible enveloping structures for facade and roof constructions. They are basically made up of flat panels that are hinged together. A new approach for a suitable joining and folding technique is the use of innovative 3D printing technologies for the development of fiber-reinforced hinges for joining the plate elements.

Aim of the research project
Convertible facade and roof constructions are often motivated by scenographic as well as building physical-energetic aspects (shading or exposure, building integrated photovoltaics). The integration of additional features in future enveloping structures for roofs and facades must not lead to higher construction weights or transport dimensions. The aim of the research project is the development of a light and efficient load-bearing envelope structure. The shape-changing shell element structures are basically composed of flat panels, which can perform relative motions and can be formed into a load-bearing structure by means of suitable joining and folding techniques. In particular, the joining technology of the individual panel elements is to be further developed using innovative fibre-reinforced 3D printing technologies. The demands on the "joints", where the forces are transmitted between the panels, are very high for reasons of mechanical stress and durability due to environmental impacts. The approach of the research project is linking the individual stiff panel components with the help of 3D-printed fibre-reinforced joints. Due to the desired shape changeability, the joints take up the functions of spatial foldable joints, whose complex geometry can be produced material-efficiently in one manufacturing step using suitable 3D printing technologies. In order to take into account the high stresses that occur, the use of fibre-reinforced 3D printing systems is preferred within the scope of the research project. The developed nodes are investigated numerically with the finite element method as well as experimentally. Validated material models will be determined by suitable experiments with 3D-printed samples. Demonstrators are used to investigate the application and load-bearing capacity of the developed joints.

Conclusion
A joining technology for lightweight and shape-changing folded plates units could be successfully developed. The technology is based on the 3D printing of joining elements using long-fibre-reinforced plastic (polyamide PA 6). The connecting elements take up the function of a hinge node that can be folded in several directions. Panels made of glass, wood, plastic or aluminium can be joined to form a load-bearing foldable structure. The additive manufacturing with local fibre reinforcement (carbon, glass or aramid fibre) makes it possible to combine different material requirements for strength and stiffness in one component and one manufacturing step. The experimentally determined material properties of the composite material enable the joints to be dimensioned to meet load assumptions. The developed demonstrators show the load-bearing capacity under short-term load. Future research work must be devoted to the investigation of the long-term load-bearing capacity of the foldable plates under real load and environmental conditions.

Key data

Short title: HiPlast

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FIGURES:

**Figure 1**: Clamping of a 3D printed flexible hinge into a test rig for fatigue experiments. 6 material regions are printed as film hinges, flexible enough for bending angles from 0° (as 3D printed) to 180° (maximum bending angle).

**Figure 2**: Photo of a 3D printed hinge and computed tomography with analysis of cavities
Figure 3: Experimental setup and finite element analysis of 3-point-bending test using 3D printed bars of PA 6 material.

Figure 4: Isochronous stress-strain relationship of creep behaviour of 3D printed PA6 tensile specimens. The curves were obtained from tensile-creep tests at applied loads of 11 MPa, 13.5 MPa, 16 MPa and 22 MPa. The curve for 10000 h was predicted by means of extrapolation of empirical fitted findley power laws.
Figure 5: Finite element analysis of equivalent von Mises stress (in MPa) in a fiber-reinforced hinge under tensile load in y-direction (gray arrow). View on cross section (symmetry plane y-z). High stresses are observed in both carbon fiber layers (2\textsuperscript{nd} and 4\textsuperscript{th} layer from bottom) which transfer the main part of load-bearing.

Figure 6: Parametric concept of dimensioning 3D printed foldable hinges with fiber-reinforcement with respect to load assumptions.

Figure 7: Photos of the demonstrator made of three six-part foldable elements in a row made of acrylic glass panels. The foldable elements can be adjusted independently from each other by a system of plastic ropes. The window coverage in the folded state is only 25\% of the coverage in the unfolded state.