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Programmable materials based on thermoplastic polyurethane and polystyrene

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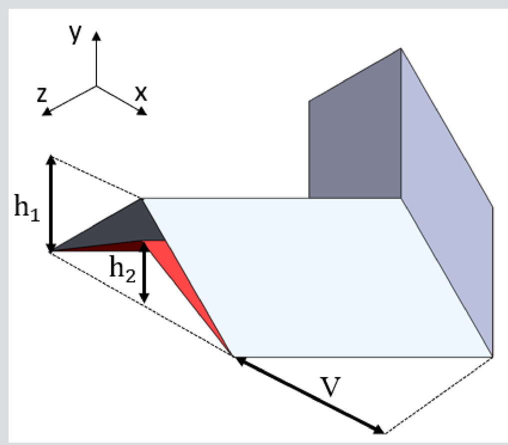
MOTIVATION AND TARGETS

- Due to the possibility to pre-define the material behaviour of Programmable Materials by designing their inner structure, they have a big potential in many fields of application, e.g., shape morphing [1, 2]. Their inner structure is formed by periodically repeated unit cells, which can be locally modified leading to a "programmed" behaviour.
- The production of Programmable Materials at a large scale is a challenge due to their hierarchical cell based inner structure.
- Target: Implementation of polymer based programmable materials which can be produced in a large scale. The used basic materials for the unit cells are thermoplastic polyurethanes (TPU), which are soft and can sustain many load cycles and polystyrene (PS), which is stiff and can bear high loads.

UNIT CELLS

- The first unit cell structure is an auxetic unit cell built up from stackable double layers with different heights h_1 and h_2 (Fig. 1). Programming by setting a defined design parameter inside the structure, offset V. The second unit cell are bistable unit cells (Fig. 2).

1)


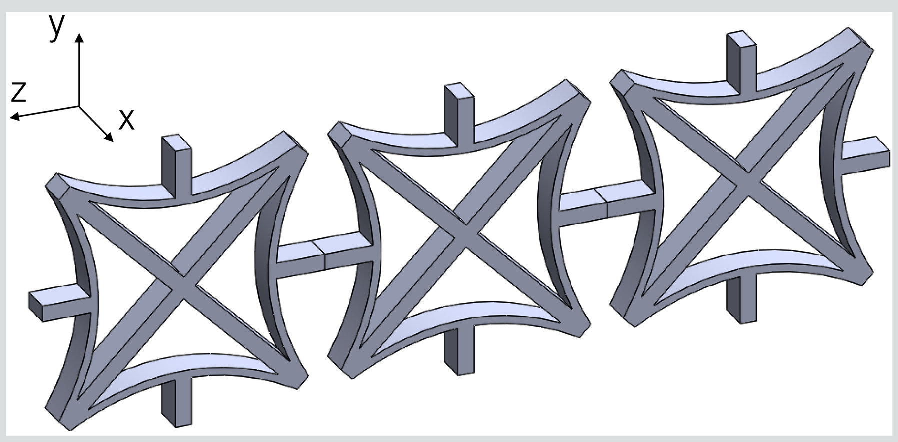
2)


Fig. 1: Auxetic unit cell based on the Miura-ori folding
Fig. 2: Three bistable unit cells

EXPERIMENTAL

- Combination of different auxetic unit cells in a non-uniform cell array model (Fig. 3) to implement a shape morphing functionality. The simulation shows the target displacement (Fig. 4). Auxetic non-uniform structure made from deformable TPU material, produced with thermoforming during a tensile test (Fig. 5).
- Good agreement between simulation and tensile test (Fig. 4 and Fig. 5).

3)


4)

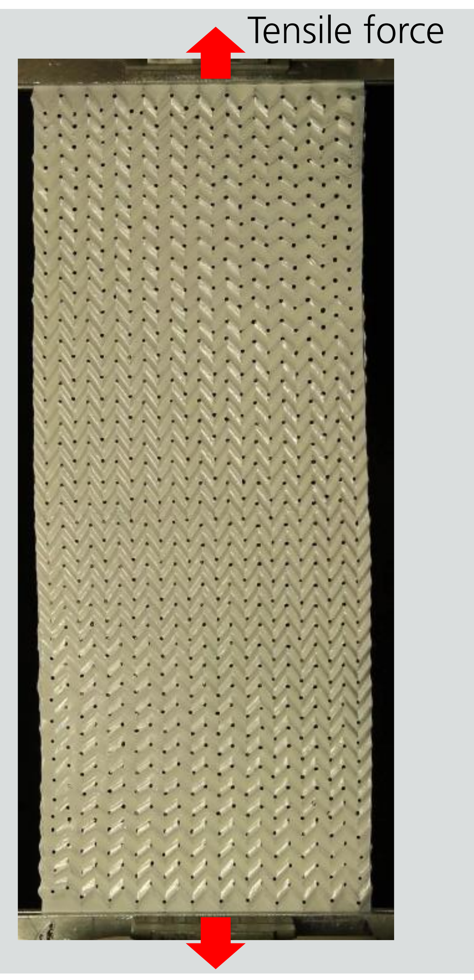

5)


Fig. 3: Model of the non-uniform structure [2]
Fig. 4: Target displacement in z-direction under tensile force in x-direction [2]
Fig. 5: Tensile test of the non-uniform structure of TPU

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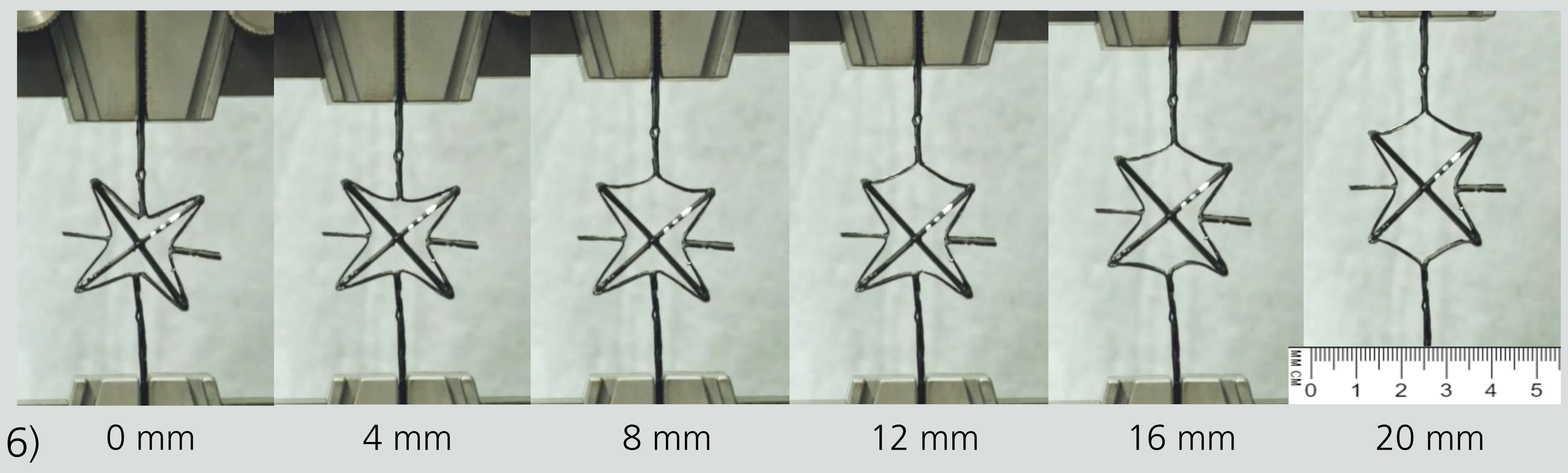

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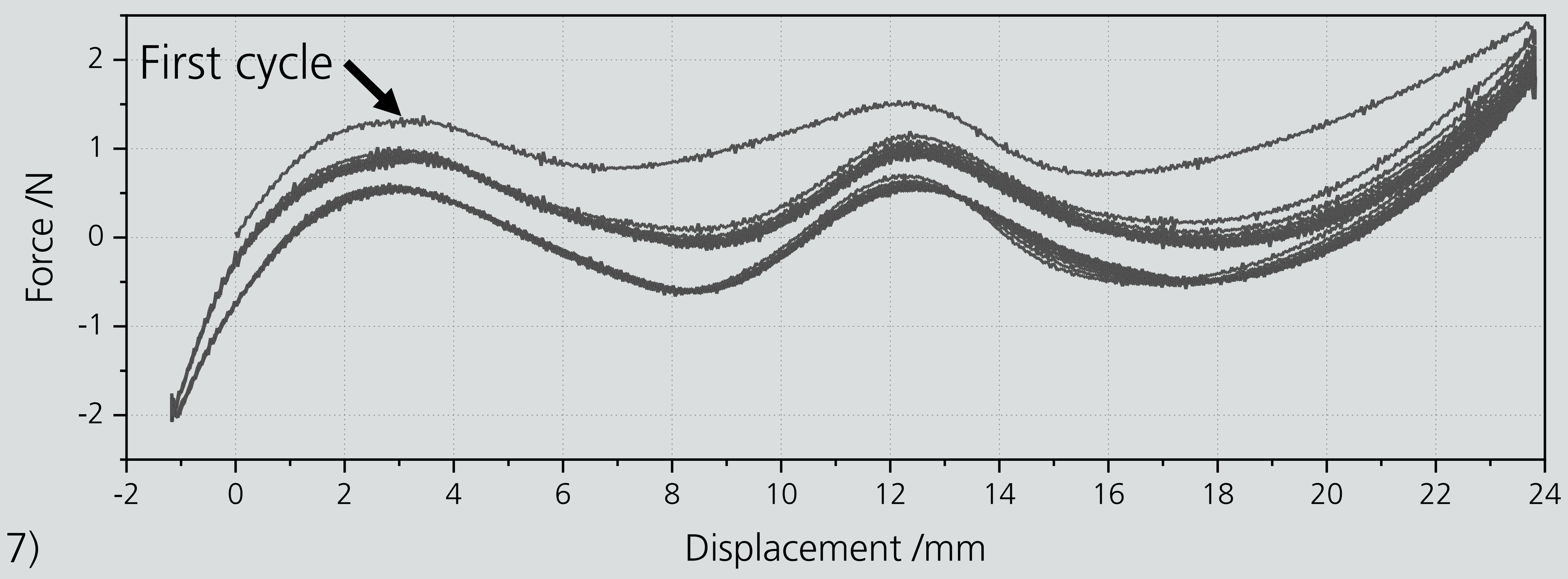

Fig. 6: Tensile test of the bistable structure of PS up to 20 mm traverse way
Fig. 7: Hysteresis curve of a bistable unit cell with 10 cycles

- Bistable unit cell made from a standard PS and PLA, which consists of a combination of thermoformed PS films and additively manufactured cross structures of PLA (Fig 6).
- For investigations of the cyclic behaviour of the bistable unit cell a tension testing machine (H&P Inspekt table blue) was used. The force was measured by a load cell with 500 N and a test speed of 2 mm/s.
- Each peak in the curve during the tensile test describes the snap-through of one half of the unit cell (Fig. 6 and Fig. 7). The first cycle from 0 to 24 mm has a higher force level than the following ones. The higher forces seen in the first load cycle may be due to the manufacturing process, i.e. surplus adhesive which detaches.

SUMMARY AND OUTLOOK

- It could be shown that a shape morphing functionality can be realised with programmable auxetic unit cells based on TPU.
- The development programmable materials requires dimensioning methods for the combination of different unit cells. The influence of the base materials must be taken into consideration. Softer materials can not achieve the theoretically achievable functionality due to their low stiffness.

Acknowledgements

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References

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