SUBPROJECT 2: Simulation-based design and robot-assisted realisation of 3D textile structures with integrated actuator and sensor networks for multi-adaptive I-FRC

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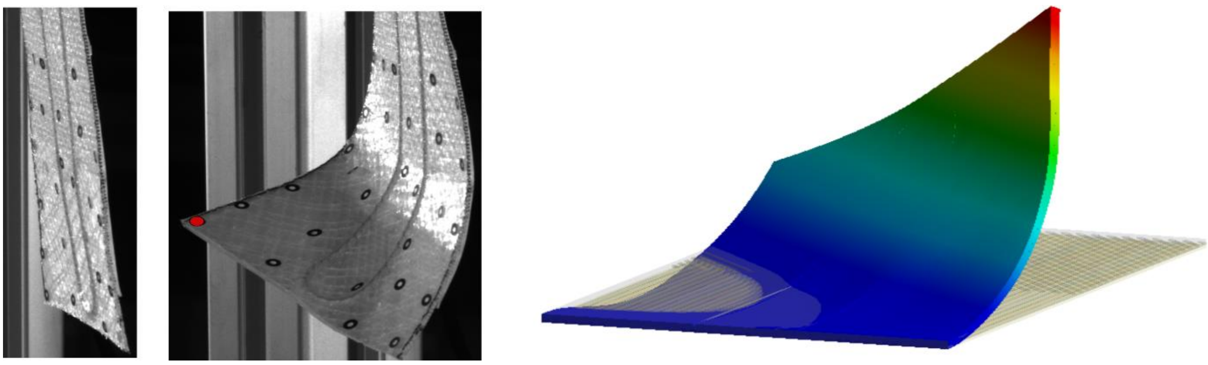
Motivation

Textile technologies play a pivotal role in integrating shape memory alloy wires within fibre rubber reinforced composite structures. Techniques such as tailored fibre placement (TFP), multi-axial knitting and weaving allow for the customization of complex architectures resulting in multi-joint structures capable of exhibiting multi-spatial motions. Simulating such complex structures explores interactions between SMA elements and the composite materials guiding the design process and facilitating performance optimization across diverse operating conditions. By predicting the deformational characteristics, the kinematics and performance of the SMA integrated composite can be controlled by considering various design parameters.

State of the art and previous research

The integration of Shape Memory Alloys (SMAs) into fibre-reinforced rubber composites introduces a new dimension of functionality, enhancing their structural performance and enabling novel applications. The combination with advanced textile manufacturing methods such as weaving, knitting or braiding enables the precise integration of SMA elements within the composite matrix, facilitating controlled deformation and shape recovery. The research efforts of the 1st cohort were directed towards the material characterization and development of fibre-reinforced elastomer composites with integrated shape memory alloy (Nickel-Titanium alloy) subjected to bending deformations [1,2]. By integrating simulation approaches such as finite element analysis (FEA), the 1st cohort predicted the motion behaviour at the structural level based on parameter studies. The research of the 2nd cohort focused on the realization of bend-twist coupling invoking the three-dimensional mechanisms on multi-joint structures. To obtain this, textile technologies such as TFP and knitting were utilized, through which the imposed fibre angles created the necessary bend-twist coupling [3]. To predict the deformational patterns, an FEA approach was considered by incorporating the newly developed Woodworth-Kaliske SMA model [4,5]. To validate the results, a multi-digital image correlation approach has been used to determine the deformations. A sample comparison is shown in the figure below. Although bend-twist coupling is realized, there exists a considerable amount of development in creating different 3D preform topologies with multi-sectional joints.



Experimental testing and simulation of bend-twist coupling of I-FRC including SMA

Scientific questions and project objectives

The objective of SP 2 is to research and optimize the actuator mechanisms based on the design of the 3D preforms to improve kinematics (deformation potential) and kinetics (actuating forces for complex 3D deformations). A design optimization based on the parameter study for these 3D preforms is to be realized using FEA and to be validated using measurement techniques. Based on these realisations, in-plane contacting and connection of actuators to form actuator networks should be developed to perform complex 3D deformations.

Integrating actuator and sensor technologies based on fiber-based textile actuators from SP 1 and SP 8, should also be considered to gain mechanical response and to emulate the complex deformations potential along with the coordination of SP 9 to control those deformation mechanisms. SP 2 should also collaborate with SP 3 to leverage the unique properties of different elastomer materials like Liquid Isoprene Rubber as a viable alternative to silicone, capitalizing on its distinct advantages in creating concentrated areas with variable stiffnesses.

References

[1] Lohse, F.; Kopelmann, K.; Grellmann, H.; Ashir, M.; Gereke, T.; Häntzsche, E.; Sennewald, C.; Cherif, C.: Experimental and Numerical Analysis of the Deformation Behavior of Adaptive Fiber-Rubber Composites with Integrated Shape Memory Alloys. Materials, 2022, 15: 582, https://doi.org/10.3390/ma15020582.

[2] Lohse, F.; Annadata, A.R.; Häntzsche, E.; Gereke, T.; Trümper, W.; Cherif, Ch.: Hinged Adaptive Fiber-Rubber Composites Driven by Shape Memory Alloys—Development and Simulation. Materials, 2022, 15: 3830, https://doi.org/10.3390/ma15113830.

[3] Annadata, A.R.; Endesfelder, A.; Koenigsdorff, M.; Mersch, J.; Gereke, T.; Zimmermann, M.; Cherif, Ch.: Evaluation of Bend-Twist Coupling in Shape Memory Alloy Integrated Fiber Rubber Composites, In: COMPOSITES 2023, https://doi.org/10.23967/c.composite.2023.010.

[4] Annadata, A.R.; Acevedo-Velazquez, A.I.; Woodworth, L.A.; Gereke, T.; Kaliske, M.; Röbenack, K.; Cherif, Ch.: Investigation and Validation of a Shape Memory Alloy Material Model Using Interactive Fibre Rubber Composites. Materials, 2024, 17: 1163, https://doi.org/10.3390/ma17051163.

[5] Woodworth, L.; Lohse, F.; Kopelmann, K.; Cherif, Ch.; Kaliske, M.: Development of a constitutive model considering functional fatigue and pre-stretch in shape memory alloy wires. International Journal of Solids and Structures, 2021, 234-235: 111242, https://doi.org/10.1016/j.ijsolstr.2021.111242.