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Development of novel, stab-resistant protective clothing using continuous fiber-reinforced additive manufacturing – Summary of the IGF research project 21622 BR

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ABSTRACT

This communication is an overview of the results of the IGF research project 21622 BR Development of novel, stab-resistant protective clothing using continuous fiber-reinforced additive manufacturing. The individual steps of the processing and the further publications are summarized.

Overview of project results

As part of the IGF research project 21622 BR, a protective panel based on bioinspired, scalable interlocking structures was designed and implemented which forms the basis for an individually manufactured stab protection vest. These protective properties were achieved through the use of additive manufacturing processes and the application of interlocking structures directly to textiles.

This resulted in an optimal combination of high protection efficiency and high wearing comfort of the vest, characterized by low weight, high flexibility and individually adapted to the human body shape.

Instead of the rigid protective plates previously used in protective vests, an innovative, body-shape-dependent segmentation of bio-inspired interlocking structures made of high-performance fiber materials is being developed. The methodological approach summarizes the analyses of people, textiles and reinforcement structure in several steps (Fig. 1).

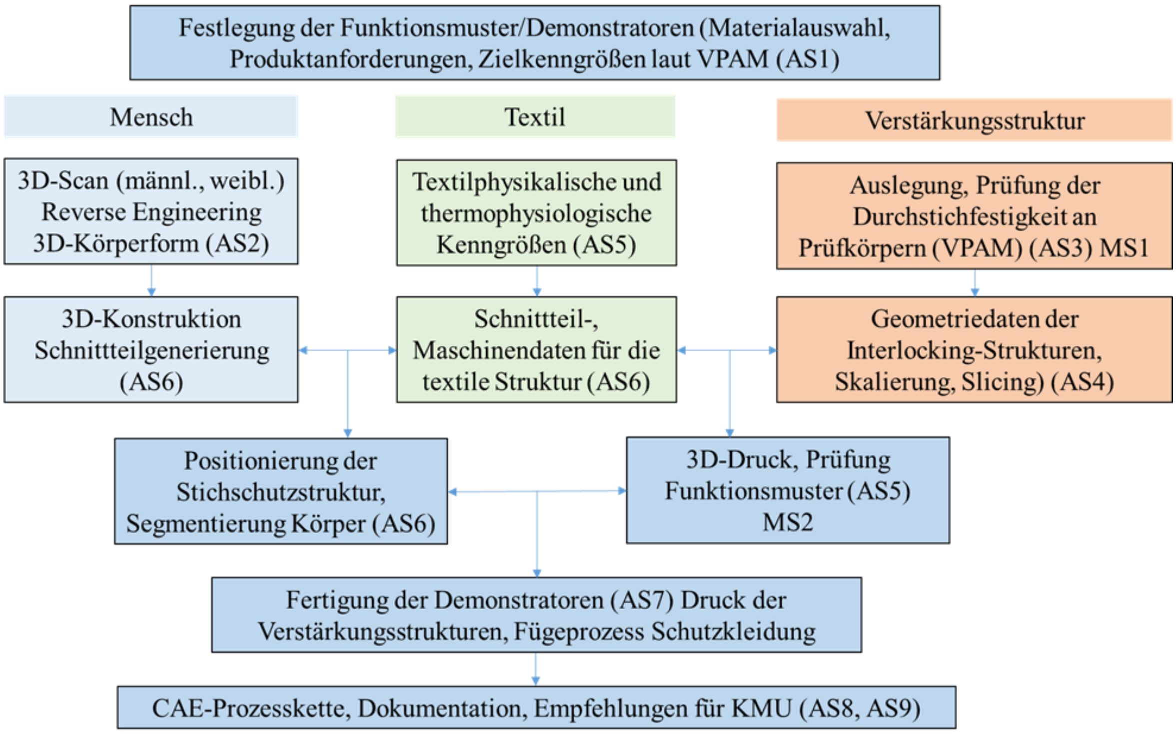


Fig. 1 Methodological approach.

In the first process step, the human body shape was transformed into 3D CAD models using 3D scanning and reverse engineering. (Fig. 2):

Fig. 2 Data preparation after the 3D body scan: a) from the initial capture of the user as a point cloud to b) the automatic generation of a homologous mesh (polygon) to c) the final representation of the untextured model.

These models form the foundation for both the generation of the cut parts of the protective vest and the placement of the stab-protecting structures. For the individual scaling and alignment of the interlocking structures, an innovative, automated method for determining the curvature of the body was developed (Fig. 3), which is based on the use of 4D scanning [1] and subsequent processing of the meshes [2].

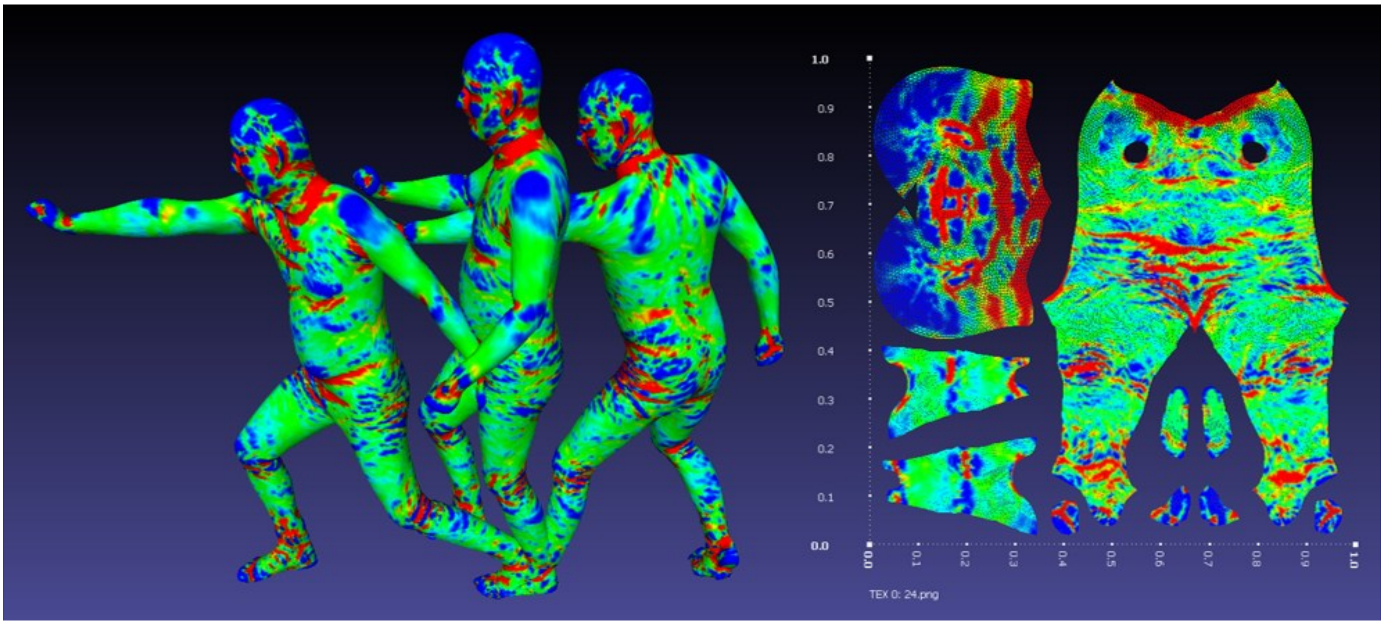
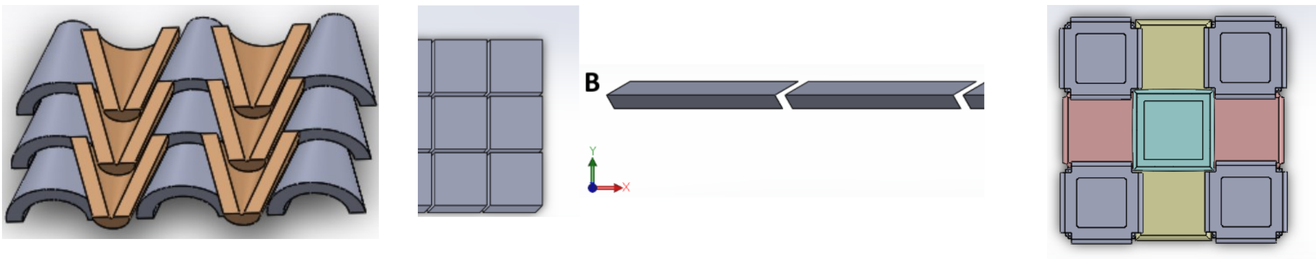


Fig. 3 left: three frames of a defensive movement with visualized curvature analysis; right: unwrapping of the 24th frame, which shows the areas of intense curvature in an unfolded representation.

This method also enables the recording and calculation of body curvatures that occur in specific movement scenarios, such as a defensive posture or when drawing a weapon [3].

Several interlocking patterns were developed for the puncture-resistant structures and produced by the additive manufacturing process Composite Filament Fabrication (CFF) (Fig. 4).



a b c

Fig. 4 View of three assemblies: a) double-layered tunnel structure; b) flat square structure with joints; c) variant of a flat structure with joints.

The samples have been tested according to the German VPAM standard. In order to achieve an optimal protective effect, various process parameters, including the number of reinforcement layers, fiber volume content, and fiber orientation, were carefully coordinated. Fig. 5 shows part of the results, from which it can be seen that both the flat pattern with a thickness of 4 mm and the convex structure with 4 mm absorbed the energy well and that the knife did not reach the maximum permissible penetration depth of 20 mm.

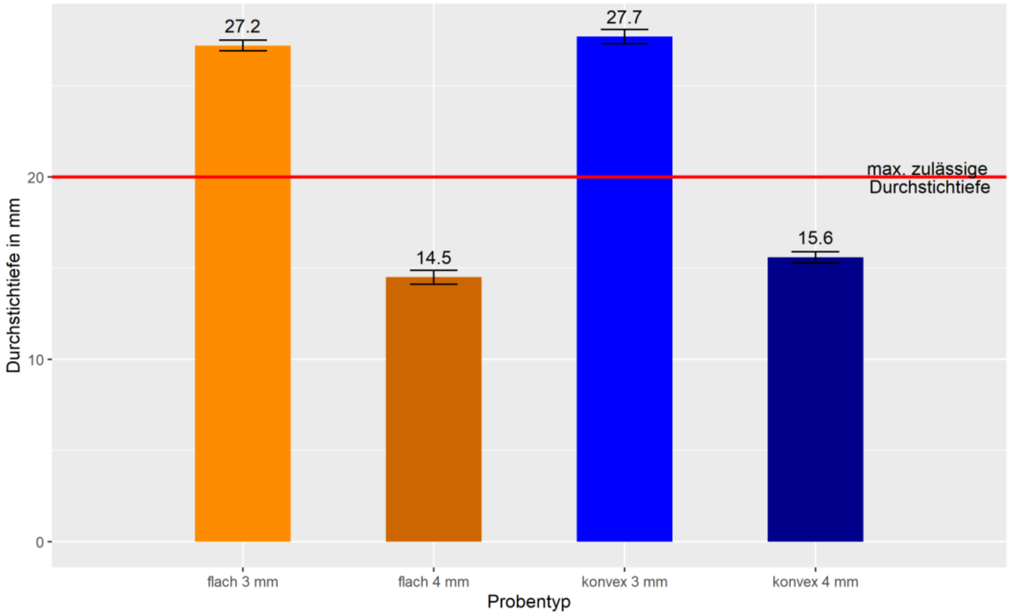


Fig. 5 Penetration depth of round and convex

As a result, protection class K1 of the VPAM standard was met. From an economic perspective, special attention was paid to the direct printing of the structures on a textile carrier material. In this context, various textiles were analyzed for adhesion with regard to their interaction with the applied high-performance polymer matrix and corresponding printing process parameters were defined. The combination of the developed interlocking structures (finally consisting of additive CFF with polymer matrix and carbon continuous fibers) and direct printing on the textile carrier material led to the creation of an individually manufactured protective panel that is specially optimized for curved body contours [4,5]. In a final processing step, this protective panel is integrated into an outer shell in terms of assembly technology. Additional high-performance materials were characterized and used for this shell. Overall, not only extended stab protection was achieved, but also an increase in ergonomic, thermophysiological and skin-sensory comfort.

In the course of the technology and functional testing, the entire process chain, starting with scanning and body curvature analysis and packaging, was systematically developed, analyzed and evaluated during the research process (Fig. 6).

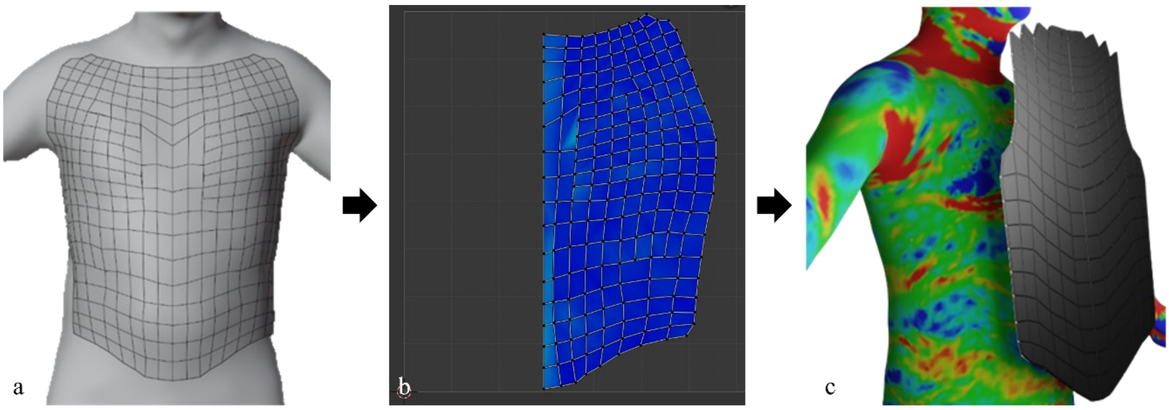


Fig. 6 Contour lines of the protective surface interactively recorded: a) 3D mesh (quad mesh) on the scanned body of the user; b) standard unwrap function in Blender of the front protective surface on one side with displayed distortions; c) body curvature and unfolding as a basis for the placement of the geometries

The end product of this research project is a custom-made stab protection vest, the core of which consists of a protective panel. This panel includes individual interlocking structures produced by additive manufacturing processes using endless high-performance carbon fibers. The individually manufactured protective vest is made up of several expandable protective segments and covers previously unprotected areas. Depending on the specific threat situation, these protective segments (shoulder, neck, flanks) can be added or removed from the vest in a modular manner. Thus, the protection of the wearer can be increased without impairing the wearing comfort.

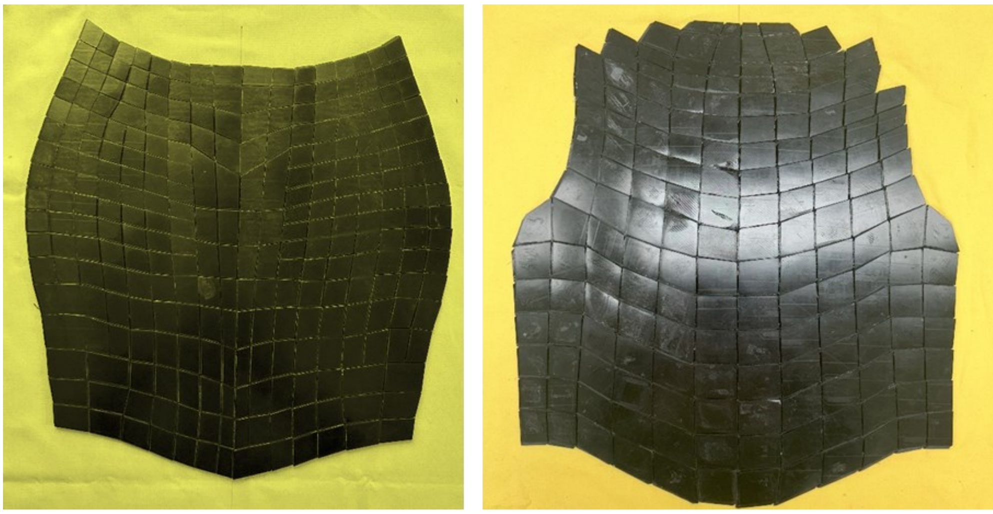


Fig. 7 Alternative FDM printing with Prusa printer directly on textile. a) front protective surface; b) rear protective surface

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