Materials Research Proceedings 28 (2023) 339-345 https://doi.org/10.21741/9781644902479-37

Forming of textile fabrics with additively assembled protective elements on the human body

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Keywords: Draping, Forming, Textile Structure, Additive Manufacturing, Textile, Rigid-Soft-Structures, Reinforcements

Abstract. Stab protective clothing is used in a wide range of applications, including military and police applications, but is also becoming increasingly important for civilian users. A relatively new way of manufacturing personal protective equipment is additive manufacturing. This makes it possible to produce new types of stab protection geometries by applying polymer layers to textiles. Such composite structures represent a mechanical system of rigid bodies with constraints, especially with large continuous protective surfaces. As a result, the wearing comfort is limited. This paper presents two methods for numerically simulating the forming of reinforced textiles with solid polymer elements over the body as part of the development and optimization process of such garments.

Introduction

Stab protection clothing is getting more important for both military and civil users, as the statistics of the national polices of several countries shows. The fact that in countries such as the UK or Germany more than 40,000 attacks with a knife or other sharp object are reported each year [1, 2] is an argument that wearing stab protective clothing is essential for various professions. There are several investigation the possibilities of improvement of the stab resistance of textile structures, based on the using non-woven fabrics [3], or triaxial textiles [4]. The properties of the fabrics are important and normally fabrics with very high density and high seam slippage resistance are required [5]. Analytical methods for investigation of the stab resistance for woven fabrics is reported in [6]. Other researchers use combination of different fiber types and found that the use of wool fibers in combinations with aramid significantly increases the stab resistance of the woven structure [7]. In the latest decade the additive manufacturing provides new possibilities for integration of protective elements in the textiles, as both laser sintering [8] and fused filament disposition of polymers [9] are applied for such applications and demonstrate that can satisfy the norms. The placement of additional solid elements increases the stab protection especially against needles and other small elements, but with the increasing of the size of these elements, can again gets negative effect in the reduction of the wear comfort of the protective clothing. This work presents a method for numerical simulation of the forming of reinforced textiles with solid polymer elements over the body as part of the development and optimization process of such clothing.

Problem Description

Safety textile products for stab protection have often additional elements, who have to stop the sharp elements and avoid the interpenetration on the human body [10]. In order to ensure some freedom of the motion, it is essential to have smaller protective plates on the areas of the body, where more motion happens or where the radius of the curvature is lower (Fig.1), and larger plates on the more statical areas and such those with lower curvature, in order to keep the protection rate higher.

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Fig. 1. Curvature areas on the human body, hier viusalised as Gaus curvature.

The protective elements can be produced with different form and integrated on the textile structure using additive manufacturing. Fig. 2 demonstrates one possible form of such protecting elements, which can be printed over knitted structure.

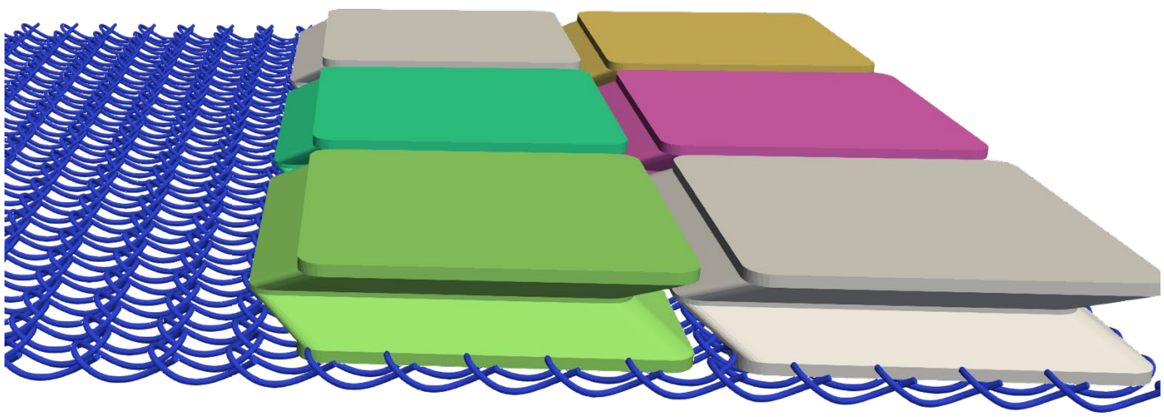


Fig. 2. Schematic illustration of a possible protective elements applied to a knitted fabric.

After determining and testing the required thickness and suitable material for the panels [9], the main task for the developer of protective clothing with such elements is the placement of the protective elements in a way, which provides the best function – in this case stab protection and the best wear comfort. In order to provide best function, elements the plates are prepared with a form which allow that they incline in each other (Fig. 3).

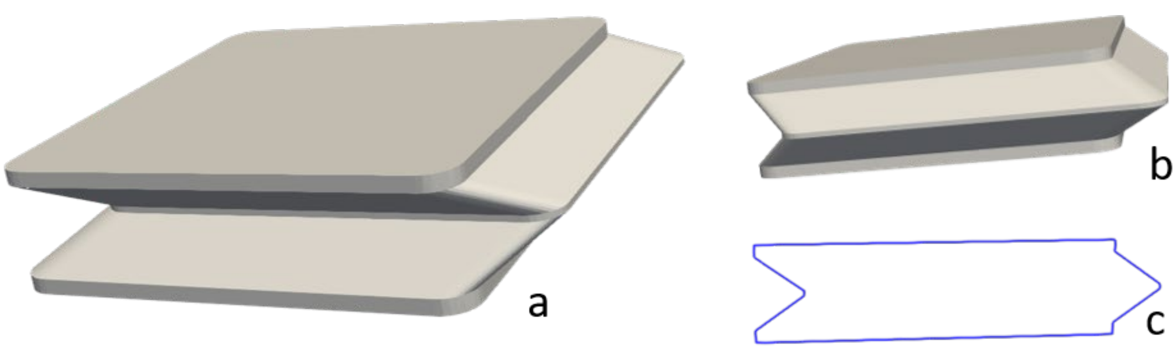


Fig. 3. Element of the protective structure a) and b) side view c) cross-section.

The convex triangle element on the two sides can incline in the concave negative elements on the other sides of the next plates and in this way to provide dense structure (Fig. 4a). Such structure retain small flexibility and allow some limited bending over curvatures which depends on the distance between the plates (Fig. 4b and 4c).

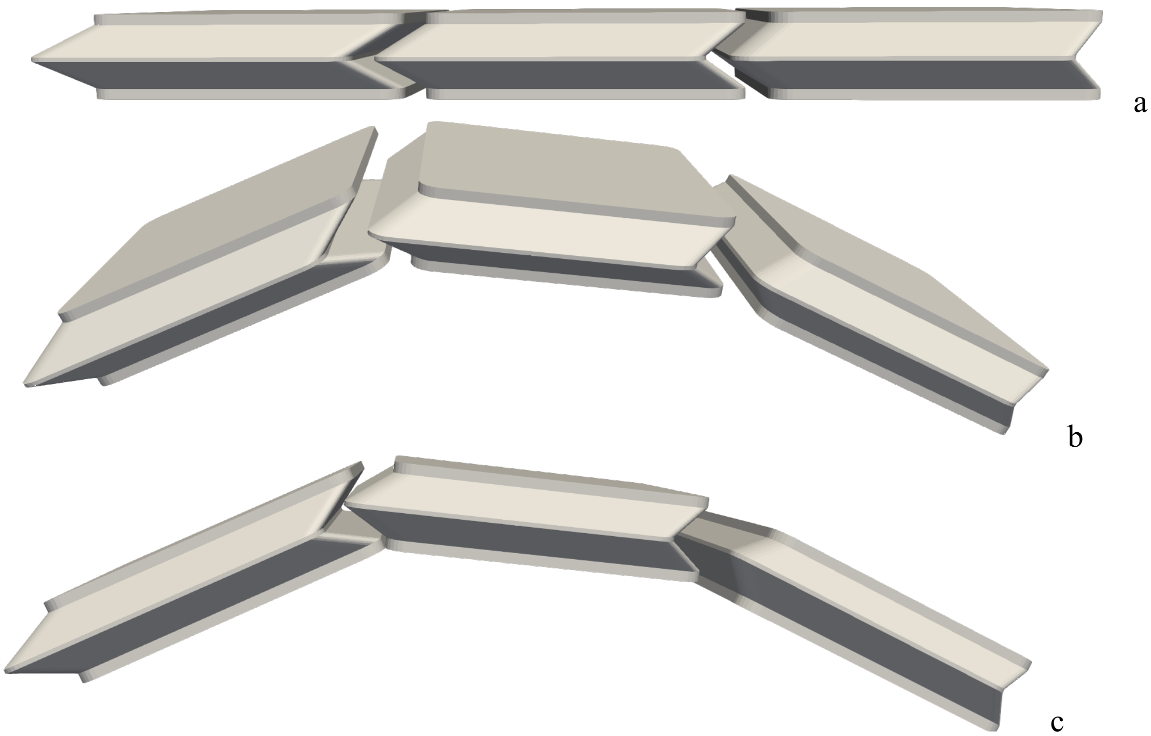


Fig. 4. Set of additive manifactured elements a) in horizontal direction b) bent with larger distance between the plates c) bent with smaller distance beween the plates.

The principal question is with which algorithms, software or method the forming over the body of such composite structure (basis textile and plates) can be simulated in order the optimal parameters for the geometry of the plates, the distance between these, the elasticity of the textile and the final pattern construction can be optimized. The common clothing CAD software can perform well draping simulation on the body, but consider all accessories as buttons in the best case as connected to the textile, but ignore their contact detection. The classical FEM software would require complex mezzo-scale level simulation of the structure, connected with the plates, but such one requires large simulation times and is not really suitable for engineering development process at the current time.

Proposed Procedure

The classical methods from the last 25 years in the area of composites forming are reported very detailed in [21]. The commonly used and reported there shell and solid shell methods could be extended for simulation of the current case of soft materials with integrated plates, but as in the current case the properties of the structure are dominated by rigid bodies, the authors decided to use another technique. The basis textile structures can be generated as 3D geometry using different software packages. Wisetex is very powerful for creation of woven fabrics [11], TexMind Weft [12] and Warp Knitting Editors [13] provide 3D geometry for the corresponding structures [14, 15]. In the current case the weft knitted structure is generated parametrically with the TexMind Weft Knitting Software and exported as STL file. 3D protective elements can be created with

Autodesk Fusion 360 and also saved as an STL file. The human body can be obtained by 3D or 4D scanning, but for the testing of the procedure is generated with MakeHuman [16].

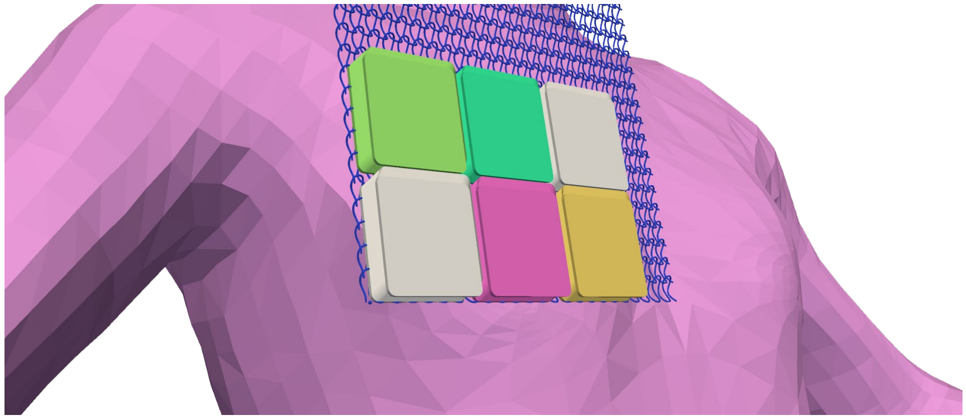


Fig. 5. Task describtion – protective elements, placed over elastic textile have to be formed to suit the human body.

For the simulation with large number of contacts and complex geometries with rigid bodies with constraints the impulse based methods are reported to provide very good performance and simplicity of the code [17, 18]. In the current case the implementation of BulletPhysics [19], especially its Python port is applied [20]. The Library allow import of the geometries as contact shapes from STL files, setting friction coefficients and all required dynamic effect. For the simulation the physical system is simplified and the complete textile layer, which provides the connection between the plates is replaced by a constrains between the plates. As suitable replacement of the complete knitted structure (Fig. 6a) two point-to-point constrains between the plates are applied (Fig. 6b).

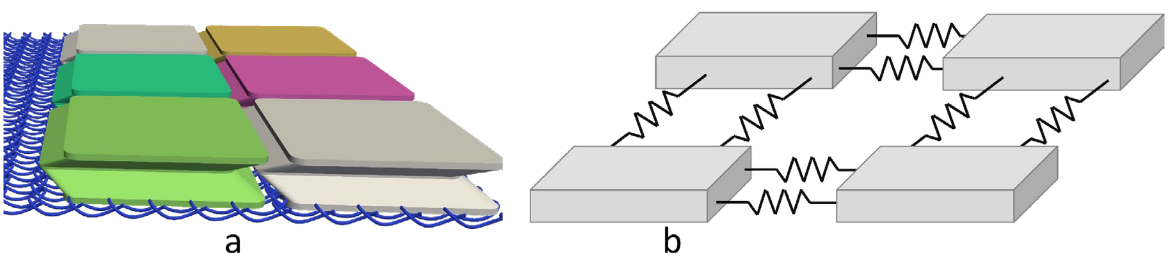


Fig. 6. Modelling of the elasticity of the knitted structure as paired springs (connecting links).

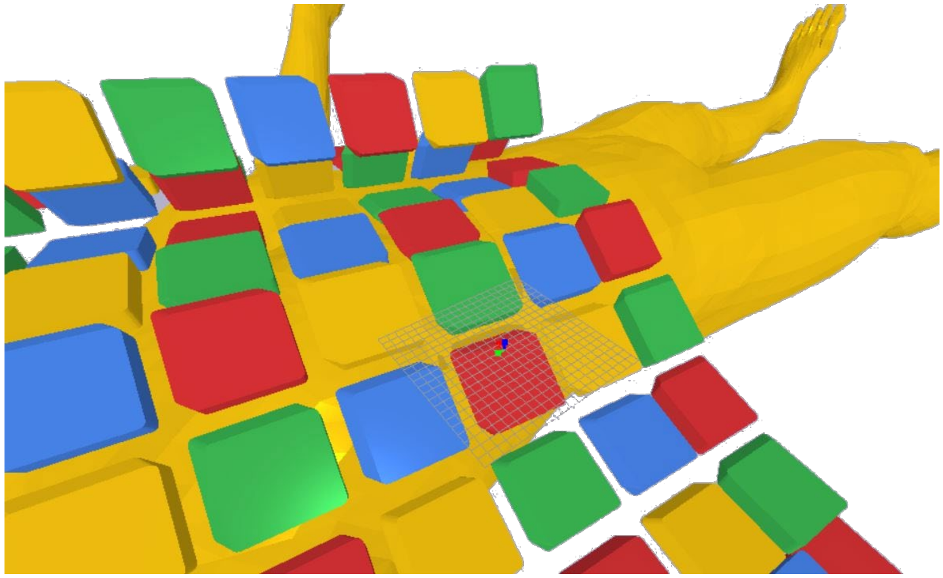
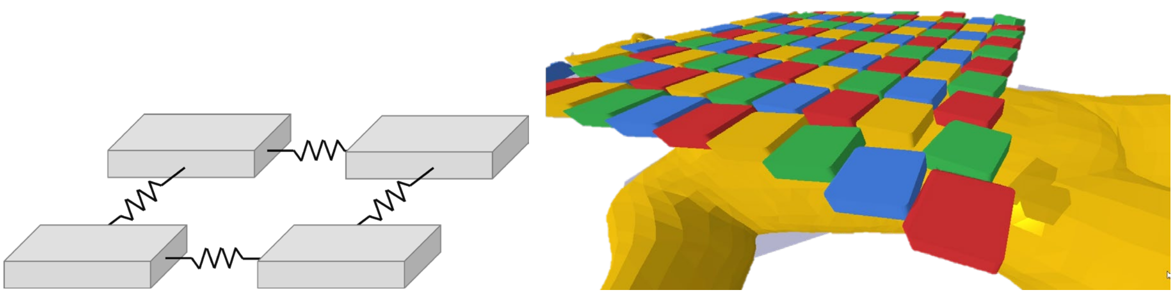


Fig. 7. Modelling of the elasticity of the knitted structure as paired springs (connecting links).

The paired two connection between each plate actually leaded to very stiff structure (Fig. 7), where the rows moves completely as a rigid type and does not allow single plates to move over the human body as it is the case if the distance between the plates is larger.

In a second trial the two pairs are replaced by only one per connection between the plates (Fig. 8a). In this way the single elements have more freedom to more around the body, as it is the case if they are produced with additive manufacturing over flexible textile structure. The starting simulation step is visualization in Figure 8b, where the plates are starting to move down to the body based on the applied acceleration.



a b

Fig. 8. a) Mechanical model of the plates, where each one is connected to the next with only one constrain b) view from the beginning of the simulation process.

After adjustment of the limits of the constraints (limitation of the maximal force) the model was able to run and simulate the process, where the initially printed elements over the flat textile will deform over the human body (Fig. 9). The principle was proven and seems that can be a basis for refinement for complex simulations, but it has shown as well several open problems, which becomes not solved until the finalization of this text. One of these is that for the proper contact simulation of the elements with concave geometry does not work properly with the simplified using of boundary box of the element and requires special treatment, forcing using the algorithms for concave triangular meshes. Applying this algorithms for the form (Fig. 3) at lower distance between the plates leads to sticking of the elements and completely limiting their flexibility. Another parameter is the limit of the maximal force in the constraints between the plates. It has the physical meaning similar to the stiffness of the connection. For low values the solver needs very long time to converge the structure and satisfy the constraints. Using high level of the maximal force the plates leads to unnatural configurations in case the plates contacts together.

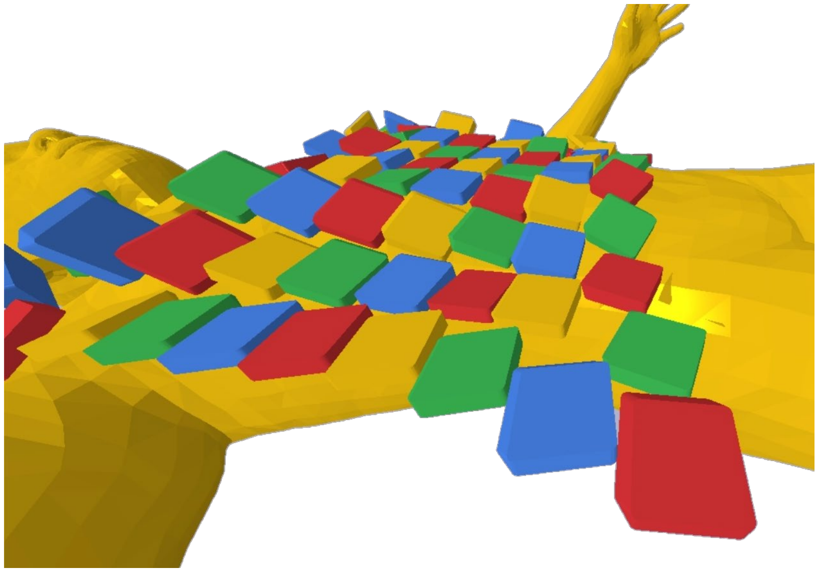


Fig. 9. Example of simulation state of the structure over the body.

Summary

Novel structures for stab protection can be produced using additive manufacturing, depositing polymer layers over textiles. Such composite structure represent mechanical system of rigid body with constraints. For the analysis and optimization of such structures, and especially the forming process when the clothing is wearied, in the current case impulse based solver is applied and two models are tested. The more natural replacement of the textile background trough two constrains parallel between each two plates leads to rigid structure and was not able to be formed over the human body with the current simulation trials. Probably more careful adjustment of the simulation parameters could give the better results. A model with only one constrain as connection between each two plates demonstrated ability to be used for forming simulation, but remains sensible regarding all model parameters. Although all difficulties and sensibilities, the models were computed on a normal home use computer with Intel 7 processor with 2,6 GHz and 16 GB RAM for few seconds, which is promising for integration in engineering software after refinement of the model and parameters.

Acknowledgments

The IGF research project 21622 BR of the Forschungsvereinigung Forschungskuratorium Textil e. V. is funded through the AiF within the program for supporting the „Industriellen Gemeinschaftsforschung (IGF)“ from funds of the Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag.

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