MULTI-RESOLUTION FINITE ELEMENT MODELS FOR SIMULATION OF BALLISTIC IMPACT ON COMPOSITE FABRIC PACKAGES

Rimantas Barauskas*, Dalia Calneryte*, Julija Baltusnikaite**, Ausra Abraitiene**

* Department of System Analysis, Kaunas University of Technology, Studentu 50, LT – 51368 Kaunas, Lithuania. E-mail: rimantas.barauskas@ktu.lt
** Lithuanian Textile Institute, Demokratu 53, LT–48485 Kaunas, Lithuania. E-mail: lti@lti.lt

Key words: Composite fabric, Modeling, Impact, Failure

Summary. Laminated textile fabrics (LTF) consist of woven or non-crimped fabric (NCF) structure bonded together by thermoplastic resin and polyethylene films over their external surfaces. Application of LTF in ballistic protection clothing offers wide opportunities because of lesser costs and ability to resist the penetration of humidity, which may substantially decrease the ballistic strength of the structure. In this work finite element models of a NCF laminate are proposed at mezzo-mechanical level, which presents the components of LTF as a structure of orthotropic shell elements. The ballistic response of the fabric against deformable 6 and 9mm bullets has been investigated.

Laminated textile fabrics (LTF) consist of woven or non-crimped fabric (NCF) structure bonded together by thermoplastic resin and polyethylene films over their external surfaces. Application of LTF in ballistic protection clothing offers wide opportunities because of lesser costs and ability to resist the penetration of humidity, which may substantially decrease the ballistic strength of the structure. Another advantage is that in NCF the aramide filaments are not weakened by crimping, which is inherent in woven structures.

In this work finite element models of NCF laminate are proposed at mezzo-mechanical level, which presents the components of LTF as a structure of orthotropic shell elements. The ballistic response of the fabric against deformable 6 and 9mm bullets has been investigated and compared against the results obtained earlier by using traditional crimped woven fabric structures.

The architecture of the model used in this work reflects the real structure of the LTF. Models have been generated at micro-mechanical (which present a small cube of 3D filament structure), mezzo-mechanical (which present yarns bundles as smallest structural units) and macro-mechanical (which present LTF as a continuous membrane) level. Numerical experiments made on micro-cubes enabled to establish average material properties used in mezzo-mechanical models. Mezzo-mechanical models in their turn served for verification of macro-mechanical ones.
The micromechanical model of a fragment of the parallel filament layer filled by resin is presented in Fig.1. Linear and non-linear finite element static analysis of the sample composite micro-cube is performed by assuming prescribed displacements and boundary conditions. On the base of average values of strains and stresses on the sides of the cube the equivalent stiffness tensors and yield stresses are obtained, which can be used for mezzo-level models. The finite element models of sub-layers of the LTF at mezzo-level are obtained by using orthotropic shell elements. Additional architectural details of the model are employed in order to present adequately the failure of the sub-layer. The failure criteria used for homogeneous shell structures are not directly applicable to composites. In this work the strips approximation is used. The strips made of orthotropic shell elements are bonded together by narrow bands of isotropic elastic-plastic elements (Fig.2), the failure of which takes place at the prescribed value of effective strain. The approach ensures homogeneous transverse stiffness characteristics of the sub-layer and simultaneously ensures the initial formation of failure lines along the filament direction. Finally, the longitudinal failure of filaments takes place as limit longitudinal strain is reached. It has been demonstrated that the narrow filling elements do not cause very small explicit time integration steps as the stiffness of the filling is much lower than the stiffness of the filaments. Usually, the ratio of the width of the filling band over the finite strip of the composite may be equal to the ratio of elasticity modules of the orthotropic shell over the filling.

The width of finite strips is not strictly prescribed. The width of the strip must ensure the convergence of the model, which is investigated on the base of comparison of dynamic responses of the structure obtained by using different widths of strips. Practically, the applicable width depends on the speed and energy of dynamic loading and on geometrical and structural properties of the ballistic impact zone.

The LTF ballistic interaction and failure model have been developed by using LS-DYNA finite element analysis software, Fig.3. Proper adjustment of element types taking part in the structure, as well as, material stiffness, plasticity and failure properties enable to achieve close-to-reality behavior of the structure. However, efforts are required in order to adjust the options and values of different failure criteria available in LSDYNA for different types of elements and materials.

Problems specific to impact-induced dynamic behavior of the LTF structure are discussed. The very nature of ballistic impact interaction implies the use of several zones of different resolution capabilities. The closest vicinity of the impact requires high resolution and failure modeling, while farther zones serve as the environment and may be modeled by structural models of lower resolution capability. However, the longitudinal and transverse wave propagation speeds have to be ensured to be the same in zones with different resolution capabilities. Non-realistic reflections of the stress waves may return back and change the interaction conditions at the impact zone. Reflections may be expected from the boundaries of the model, as well as, from the junction lines of zones of different resolution properties.

Several static and dynamic physical experiments have been carried out and compare the basic features of behavior of the model against the reality.
Fig. 1. Micro-level photo and micro cube FE model

Fig. 2. Ortotropic strips and filling bands

Fig. 3. Principal scheme of mezzo-level model and failure views of sub-layers