FINITE ELEMENT ANALYSIS OF BALLISTIC RESPONSE OF LAMINATED TEXTILE FABRIC MULTILAYERS IN LS-DYNA

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ABSTRACT

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 9 mm bullets has been investigated.

Key Words: high-velocity impact, multi-layer fabric, finite elements, mezzo-mechanical model, LS-DYNA

1. INTRODUCTION

The rapid rise and variety of new textile materials on the market [1], promotes the further theoretical and experimental investigations of fabric packages by establishing their properties and regularities. The design of textile fabric structures and their packages can be significantly facilitated by means of deeper understanding of the behavior of a single or several fabric layers during their interaction with bullets. During the last decade numerous researches have been carried out on the ballistic impact of high strength fabric structures [2 – 5].

In [6] a computational model of interaction of a deformable projectile (bullet) against a multilayer woven structure has been developed, which enabled to simulate shooting experiments performed in order to test the ballistic strength of the textile body armor. The finite elements (FE) model of the woven fabric has been created by using orthotropic shell elements, the properties of which have been selected in order to represent the behavior of real paraaramid yarns. The holdup of a bullet and the shooting-through the multilayer fabrics have been simulated.

Application of laminated textile fabrics (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. LTF consist of woven or non-crimped fabric (NCF) composites¸ which have a complicated and irregular internal architecture, heterogeneous not only at micro-scale but also at meso-scale, which may affect their mechanical performance under loading [7].

The aim of this research is to develop the finite element model of laminated textile fabric subjected to ballistic impact by 6 and 9 mm 300 m/s bullets. The approach to the model development follows the one presented in [6], which employs a mezzo-mechanical approach by presenting yarns and layers of filaments by means of orthotropic membrane elements. New challenges encountered in laminated textiles modeling are due the necessity to model the resin bonding by properly adjusted contacts and constraints in LS-DYNA.

2. FINITE ELEMENT MODELS

2.1 General approach

The internal structure of parts and components interacting in the ballistic impact is highly heterogeneous. Modern finite element programs have extensive element libraries and are able to model complex internal and external interactions, however, the presentation of computational models of LTF structures requires much effort and adjustment/identification of model parameters, which very often cannot be obtained by direct measurements. A number of computational and physical experiments are necessary to make in order to obtain verified and validated models.

The basic parts of ballistic interaction are bullets and LTF layers. Though geometrical and physical models of bullets can be easily generated in any finite element computational environment, the parameters describing the dynamic properties of materials have to be identified via comparison of computed results against physical experiments. For this purpose we analyzed numerically and experimentally the process of shooting and imbedding of the lead bullet into the thick lead plate. The obtained models were further used in models of their interaction against LTF structures.

Models of LTF have been generated at mezzo-mechanical (which presents yarns bundles as smallest structural units) and macro-mechanical (which presents LTF as a continuous membrane) level. Mezzo-mechanical models served for verification of macro-mechanical ones. On the other hand, certain parameters of the model have been identified by using results of analysis of shot-through LTF layers, such as geometrical shape and parameters of the damage zone.

2.2 Bullets

The models of 6 mm lead bullets and 9 mm full metal-jacket bullets have been investigated. The 6 mm lead bullet has been presented as a solid lead body, the dynamic material properties of which had to be identified. At ~300 m/s impact velocity the problem is classified as high velocity contact-impact interaction problem where the yield stress value is assumed to be dependent upon the strain rate in accordance with the Cowper-Symonds material model:

, (1)

where: σ_Y, σ_{Y0} - yield stress limits of the material defined with and without the influence of strain rate $\dot{\varepsilon}$; C and p – constants.

Fig. 1, a, b presents the pre-impact and post-impact shapes of the lead bullet, the constants C and p and plasticity model of which have been identified via computational and physical experiments.

2.3 Finite element models of fabric layers

The mezzo-mechanical models of ballistic interaction models of woven textile structures are generated by presenting explicitly the contact interaction among warp and weft yarns (Fig. 2, a). Simultaneously the contact interaction between the bullet and the yarns is presented. Failure of paraaramid yarns is determined by elastic 4-5 % strain value.

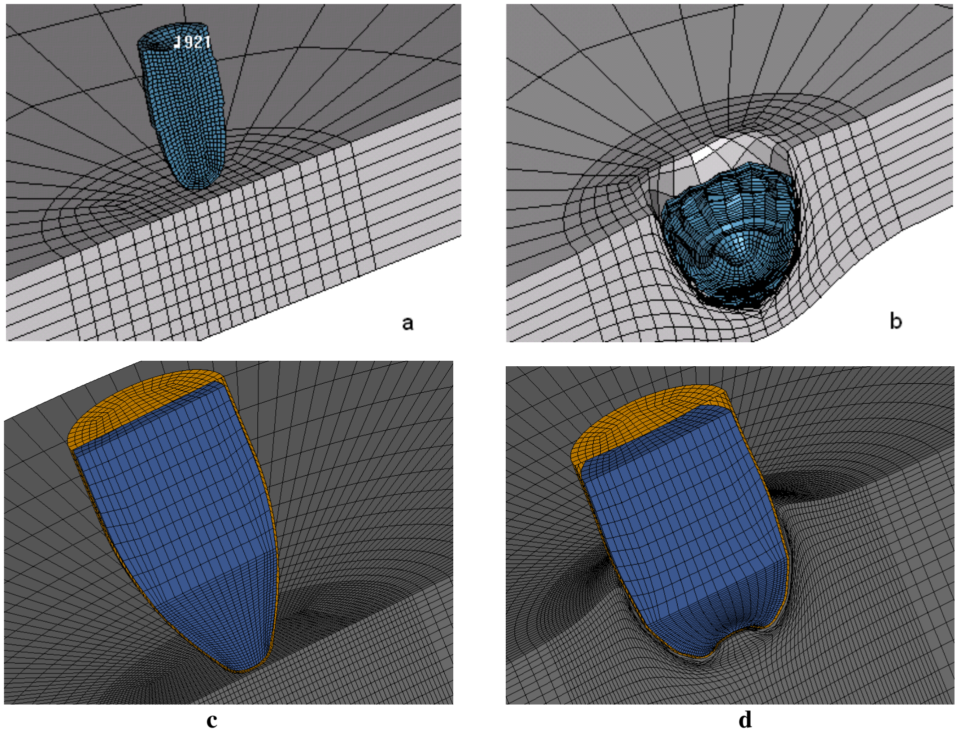

Figure 1. The initial and final shapes of bullets interacting with lead plates:
a, c – initial geometry of a lead bullet at velocity 270 m/s (a) and full metal jacket bullet at velocity 73m/s (c);
b, d – final deformed configurations, satisfactory agreement with experimental data

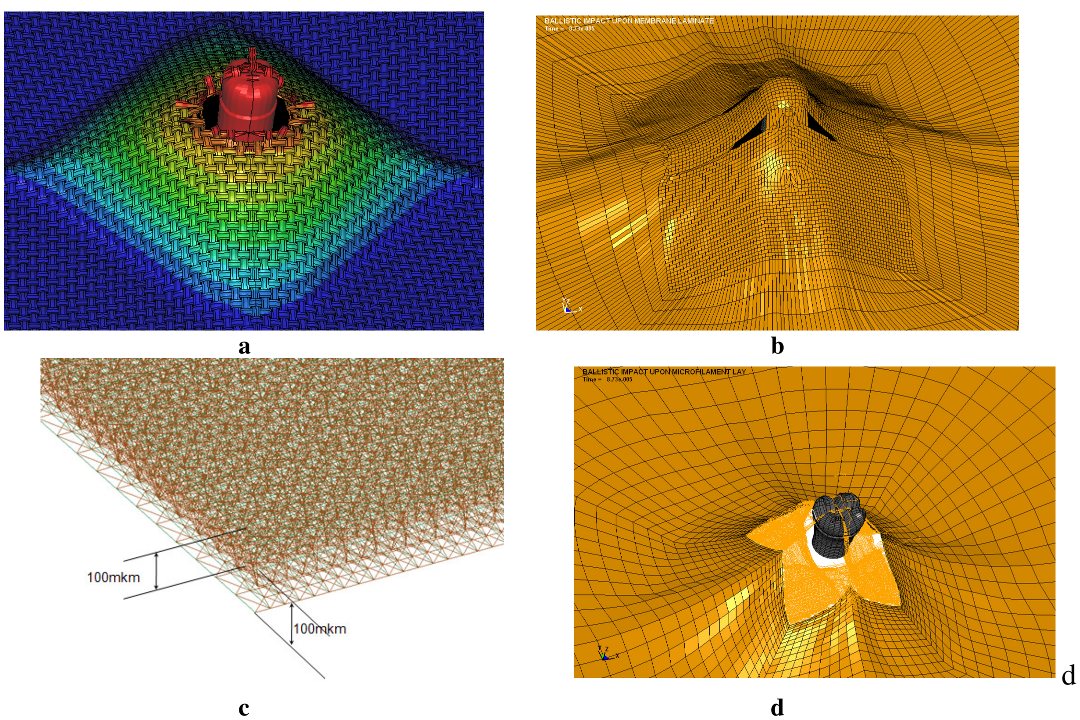

Figure 2. Finite element simulations of shooting through the woven textile structure (a), the orthotropic LTF model (b) and the mezzo-mechanical LTF model (c, d)

The models of non-crimped yarn structures of LTF possess new features when compared with woven structural models. Though contact interactions of the filaments are still present, the LTF has no explicitly presented yarn structure. Instead, layers of filaments are fastened together by means of elastomeric pitch. Each layer may be presented as orthotropic membrane by using the *MAT_LAMINATED_COMPOSITE_FABRIC material model in LS_DYNA (Fig. 2, d). Complex failure options are provided for this material, however, the only one choice of element deletion condition according to limiting value of stress intensity requires to be careful when setting the failure limit strain. Alternative more detailed models, which present yarn bundles structure in the vicinity of the impact have been generated (Fig. 2, b, d), which enable to verify the layer failure conditions in accordance with the results of numerical experiments performed on detailed models.

3. CONCLUSION

Newly developed models of ballistic interaction may be applied for simulating the testing shots performed on ballistic protection clothes, the protection function of which is based on application of multilayer textile packages integrated into the clothes. The numerical experiments enable to predict approximately the ballistic limit of newly designed textile packages.

4. REFERENCES

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