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Suitability of numerical model from low to high velocity impacts against KM2 fabrics with isotropic hypothesis

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ABSTRACT

In order to predict the effect of projectile impacts on aramid fabrics with a low computational cost a 1-layer mesoscopic model has been developed. This model has been studied with orthotropic and isotropic properties and have been compared each other. Similar results have been obtained in both cases in a range from low to high velocities (up to 1763 m/s). The comparison shows a very good fit for both models in the predictions of residual velocity and absorbed energy which rely on the experimental results of Park et al. (2014). Ballistic limit has been studied on both cases with good result considering experimental results of Rao et al. (2009) and Duan et al. (2005). Finally, the deformation induced by the projectile has been studied too. Furthermore, in this paper are presented the advantages and the limitations of each methodology.

1. Introduction

During the last decades the synthetic materials have increased their importance on all kind of applications such as structural reinforcement [4,5] and individual protections like helmets [6,7,8], bulletproof vests or soft armors [9,10,11]. In this second case, one of the most commonly used materials has been the aramid fibers, specially the Kevlar® 29, Kevlar® 49 and Kevlar® KM2. Aramid fibers offer excellent mechanical properties for protections against impact due to its high strength, Young's modulus and strength-to-weight ratio. These characteristics allow a good absorption of energy before its failure [12] and reduce the body trauma caused by bullet impact [13], for example. The material has been studied from a large quantity of authors with the objective of define the mechanical properties and its response against any kind of loads, especially on high-rate loads.

To determine how much protective is a material against mechanical impacts it is essential to define its ballistic limit [2,14] or the quantity of absorbed energy until its failure [15]. Nevertheless, to achieve these properties it is necessary a large number of experimental tests. To reduce the quantity of them, and its associated cost, numerical simulations of impacts have been used.

The fabric mesoscopic models developed in this paper has been inspired of the works of Rao et al. [2], Nilakantan et al. [16], Ha-Minh et al [17] and T.-L. Chu et al. [18]. In 2009, Rao et al. [2] proposed a numerical model of impact considering a spherical projectile as a rigid body against a high-strength plain-weave KM2 fabric developed under LS–DYNA software to study the influence of friction and material properties on ballistic performance. In 2010, Nilakantan et al. [16] published a finite element model using a yarn level architecture to capture the complex projectile-fabric and yarn-yarn interactions.

In 2011 Ha-Minh et al. [19] developed a 3D impact model applied to 3-layers KM2 fabric with a thick of through the finite element code RADIOSS with 84853 shell elements. The study was centered on the effects of boundary conditions on damage mechanisms in the fabric against impacts with perforation and without perforation. Nevertheless, the computational time in all cases were quite large, from 1 h to 8 h. In 2013, C. Ha-Minh et al. [20] was studying the physical and mechanical phenomena during a ballistic impact on 2D Kevlar KM2® plain-woven fabric comparing a mesoscopic and macroscopic models with shell elements. Numerical results of woven damage and residual velocity given by both models were discussed and compared with experimental impact tests from literature. For the impact conditions considered, both approaches offered a quite good accuracy in the determination of residual velocity. These models took between 8 and 35 h depending on the model used. Because of the large computational time, the authors underlined the need to develop a correct macroscopic approach which allows to study the ballistic impact of a complete armor with a reduced calculation time. The average front area of a medium bulletproof vest is around of 140,000 mm^2. Taking into account the mesoscopic numerical model of Ha-Minh et al. [19] which has 52.8 × 52.8 mm^2 with 84853 elements for 3 layers, only the front part of the vest would need around 1.4 million elements per layer using a mesh like that. In order to make

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