Ballistic Performance of Hybrid Nonwoven/Woven Polyethylene Fabric Shields

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ABSTRACT

In the last years, new lightweight composite materials have progressively replaced conventional metallic components in certain industries such as automotive, marine or aeronautical. In the particular case of ballistic protection, dry fabrics made up by high strength fibers represent the most outstanding solution. They can be divided into woven and nonwoven fabrics depending on the architecture of the fibers. In the former, fibers are bundled in yarns weaved following a regular pattern, while fibers form a disordered network consolidated by means of thermal, chemical or mechanical bonds in nonwoven fabrics. The combination of both woven and nonwoven fabrics in hybrid laminates is an innovative solution to arrest fragments within a wide range of calibers. In general nonwovens are stacked facing the projectile to enhance the load transmission into the woven fabric. In addition, there are reports of changes in the mechanical response of the nonwoven fabric due to the interaction with the woven layers at the rear of the laminate. This synergistic contribution to the impact resistance emerging from the nonwoven/woven laminate lay-up has not been studied in detail and this is the main objective of this research.

To this end, the ballistic response against small projectiles of a hybrid laminate made up of a front layer of a needle-punched nonwoven fabric and several layers of a woven fabric was analysed from the experimental and numerical viewpoint to understand the peculiar deformation and fracture mechanisms of this system. Two commercial fabrics were used in this investigation. The first one was a needlepunched nonwoven fabric denominated Fraglight NW201 (DSM) manufactured by Dyneema SK75 fibers of approximately 60 mm in length. The second material was 4 harness satin polyethylene woven fabric made up with Dyneema SK65 fibers. The configuration of the hybrid shield for the impact tests included 1 nonwoven fabric layer (NW) supported by 4 woven layers (W) leading to a stacking sequence [NW/0_W/90_W/0_W/90_W].

Impact tests were carried out with a gas gun using a pneumatic launcher SABRE A1. The projectile was a steel sphere with 5.5 mm in diameter and the impact velocity was in the range 300 to 400 m/s. Additionally, the mechanisms responsible for the ballistic performance of the hybrid shield were ascertained by means of numerical simulations. Simulations were carried out using the finite element method in Abaqus/Explicit within the framework of large displacements and rotations with the initial unstressed state taken as reference. Different finite element approaches and constitutive equations were used to describe the woven and the nonwoven fabrics. On the one hand, the woven fabric was simulated at the mesoscale including every single yarn in the 4 harness weave. The polyethylene yarns were modelled as transversally isotropic linear elastic solids. On the other hand, the mechanical behavior of the nonwoven fabric was given by a multiscale constitutive model able to take into account the complex deformation and fracture mechanisms of this material under quasi-static in-plane deformation.

Impact experiments showed that the energy absorbed by the woven fabrics was very low as the projectile penetrated easily in between the yarns due to yarn slippage. The polyethylene nonwoven fabric was able to absorb more energy during impact by the in-plane deformation of the fabric. Final penetration of the target was accomplished by tearing around the projectile as the fibers were pulled out from the entanglement. The deformation and failure mechanisms obtained in the numerical simulations were in agreement with the experimental results and they provide more details about the origin of the efficient behavior of the hybrid shield. Initially, the projectile could not penetrate in between the yarns of the woven fabric because it was stopped by the nonwoven fabric. On a first stage the energy was transmitted to the woven yarns through the nonwoven fabric, avoiding the local penetration observed in the woven shield. Second, the projectile surrounded by the nonwoven fabric slipped through the yarns of the woven fabric and the contribution to the energy dissipation of the latter was reduced. However, the energy absorbed by the nonwoven fabric increased rapidly from that instant due to the confined deformation of the nonwoven in front of the projectile until the final penetration, taking advantage of the energy dissipation capability of the nonwoven fabric.