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Perforation of flexible laminates by projectiles of different geometry

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Abstract

This paper investigates the response of flexible laminates to ballistic impacts by projectiles of various geometries, namely, flat-ended, hemispherical, ogival (CRH 2.5) and conical (30° half-angle) projectiles. The laminate of interest is Spectra Shield® comprising [0°/90°] extended chain polyethylene filaments embedded in a thermoplastic resin. Ballistic tests show that flat-ended projectiles cut the laminate through a shearing action, effectively punching a circular hole in the laminate whereas hemispherical projectiles perforate the laminates by stretching the Spectra filaments to failure resulting in a rectangular hole in the laminates. While the manner in which they are perforated are different, many similarities are observed in specimens perforated by flat ended and hemispherical projectiles such as the formation of a generator strip, the extent of delamination, the creasing of the laminate, tearing of the laminate at the edges, etc. Ogival and conical projectiles, on the other hand, perforate the laminates with minimal delamination and tearing of the specimens. Interestingly, the region of the specimens affected by the projectiles appears to increase in size instead of becoming more localised at higher impact velocities as often reported for most ballistic impacts events, including the ballistic perforation of woven fabric. This suggests flexible laminates are more effective in dissipating energy than woven fabric in the application of flexible armour.

Keywords: Spectra Shield; Flexible; Armour; Laminate; Ballistic

1. Introduction

Flexible protective materials against ballistic impacts have made significant advances over the past few decades. Flexible armour is preferred for personnel protection because they offer less

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restriction to the mobility of users. Drapable armour was initiated by using high-strength materials instead of traditional yarns with established textile manufacturing techniques. Yarns made of nylon were the first generation of high-strength materials to replace natural threads in fabrics for ballistic protection applications. Following the introduction of nylon, research on flexible high impact resistant systems has largely focused on the search for stronger materials. The discovery of aramid marked another significant jump in the performance of fragment resistant flexible materials. Improvements in flexible armour are mainly a result of stronger materials. Fabric fabrication techniques have remained largely similar to traditional fabric weaving methods. Of the different woven architectures, it was recognized at a very early stage that the plain weave was the most efficient in dissipating impact energy because the simple weave introduces the most cross-yarn interactions. The yarn crossover points facilitate the dissipation of impact energy to yarns not in direct contact with the projectile.

Together with the search for stronger materials, the current trend in the research of ballistic-resistant materials is to look at novel ways to incorporate new materials into an armour system while maintaining drapability. However, it is no longer possible to make significant improvements merely through simple changes in processing techniques or in materials substitution. In yet another step towards higher levels of protection against ballistic impacts, flexible laminates were introduced. These comprise continuous high-strength filaments embedded in a thin film of flexible resin. Their advantage over woven fabrics is the absence of crimp in the filaments. Crimp is the undulation in each yarn as it runs over and under alternate crossover yarns. Crimped yarns need to straighten out before they start to stretch and become effective in resisting the projectiles. This gives rise to excessive deflection leading to blunt trauma. The straight filaments in flexible laminates extend immediately on impact and quickly spread the energy to the surrounding materials. By involving more material in the energy absorption process, it reduces blunt trauma and is able to defeat projectiles of higher energy than woven fabric. An armour system of flexible laminates will include multiple layers of unidirectional laminas at different directions because a unidirectional laminate is weak perpendicular to the filaments.

While literature on woven fabric material for ballistic resistance has grown substantially over the past few years, there is still much to be reported on the ballistic performance of flexible laminates. The results of ballistic tests on flexible laminates, namely, Spectra Shield® laminated composite roll (LCR) is presented in this article. The objectives are to understand how small projectiles perforate 2-ply flexible laminates and to study the effects of projectile geometry and impact velocity.

2. Spectra Shield® LCR

The material used in this study is Spectra Shield® LCR by Honeywell. It is a $0/90^\circ$ flexible laminate of unidirectional Spectra-1000 fibre sandwiched between two thermoplastic films. Spectra-1000 is an organic fibre made of extended-chain polyethylene (ECPE). Spectra Shield® LCR has an areal density of $150\ \mathrm{g/m^2}$ and is of 0.18 mm thickness. Reports of relevance are limited and focus on the characteristics of the individual constituent polyethylene fibre and hard Spectra Shield composite panels.