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Modelling crimp in woven fabrics subjected to ballistic impact

V.B.C. Tan*, V.P.W. Shim, X. Zeng

Impact Mechanics Laboratory, Department of Mechanical Engineering, National University of Singapore, 9 Engineering Drive 1, Singapore 117576

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Abstract

Woven fabrics are widely used in flexible armour systems for protection against fragments and projectiles from small arms. The woven architecture introduces crimp or undulations in the yarns as they pass alternately over and under orthogonal yarns. An undesirable effect of crimp is excessive deflection in fabric armour during impact. The numerical results of ballistic impact and perforation of woven aramid fabric are presented in this paper. The fabric is modelled as a network of nodal masses connected by one-dimensional viscoelastic elements. The focus of the computational simulation is to compare two different ways of incorporating yarn crimp into the fabric model. Tensile tests on strips of the woven fabric show an initial toe region in the load–deflection curve before the curve asymptotically converges to an approximately straight line beyond a certain strain. The first method of introducing crimp into the fabric model is to include the toe region of the load–deflection curve in the constitutive equation describing the viscoelastic elements. The second method to account for crimp is to physically reflect the woven architecture in the fabric model by arranging the chain of linear elements that define each yarn in a zigzag manner.

Keywords: Woven fabric; Crimp; Ballistic impact; Numerical simulation

*Corresponding author. Tel.: +65 6874 8088; fax: +65 6779 1459.
E-mail address: mpetanbc@nus.edu.sg (V.B.C. Tan).

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1. Introduction

Woven fabrics constructed from high-strength polymeric fibres are widely used in flexible personal protection systems. They are also effective for the containment of high-speed fragments or munitions to shield critical components in aircrafts and vehicles. Improvements in the ballistic resistance of high-strength fabric armour systems have largely been due to advances in the production of stronger fibres. There are now many polymeric fibres with exceptionally high stiffness and high strength to weight ratios. Examples of materials that are commercially available include aramids (eg. Kevlar®, Twaron®), ultra high molecular weight polyethylene (eg. Spectra®, Dacron®), PBO fibres (e.g. Zylon®) and PIPD fibres (also known as M5®). In addition to the mechanical properties of the fibres, it is reported that the energy absorption capability of fabric armour also depends on its weave architecture, number of fabric plies, areal density and surface treatment of yarns. The ballistic resistance of a fabric is also a function of factors not related to the properties of the fabric, such as impact velocity, impact angle, projectile shape, boundary conditions, etc. A number of studies have been carried out to characterize the ballistic performance of fabrics and to identify key parameters that affect their impact resistance. A comprehensive review of recent research into fabric armour has been reported by Cheeseman and Bogetti [1]. They also presented a detailed description of factors affecting their performance.

The effects of yarn crimp on the impact response of woven fabric are presented in this paper. Crimping in yarns is a distinct characteristic of woven fabrics and has been identified to have an important effect on fabric response to impact loading. When a projectile strikes a fabric, the initial stage of fabric deformation simply causes crimped yarns to straighten. Minimal resistance is presented to the projectile. The fabric only starts to resist the projectile when the yarns have straightened and begin to stretch. Crimp can give rise to excessive transverse deflection and consequently increase blunt trauma.

Ballistic fabrics normally have different levels of crimp in warp and weft yarns because of the weaving process, resulting in weft yarns having lower levels of crimp than warp yarns. This is believed to cause weft yarns to break preferentially to warp yarns during ballistic impacts. To mitigate this phenomenon, Chitrangad [2] proposed a hybrid fabric using fibres with higher failure strain in weft yarns than warp yarns to delay the breakage of weft yarns. New generation fabrics for ballistics applications are now manufactured with equal crimp in weft and warp yarns so that yarns in both directions are loaded equally during projectile impacts. This has resulted in better energy absorption capability.

Apart from actual ballistic tests, computational simulation has also contributed significantly to a better understanding of the mechanisms involved in the impact and perforation process. Yarn crimp is normally included in computational models of fabric because its effects are not negligible. In the current study, two different ways of representing yarn crimp in numerical models of woven fabric are presented and the results obtained from the two methods are compared.

2. Twaron CT716

Ballistic tests were conducted on a plain woven fabric (Tawron® CT716) to evaluate the accuracy of the fabric models. CT716 is made from aramid fibres and its properties are given in