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# The features of finite-element modeling of a structural element of flexible woven composites

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**Abstract**

The features of finite-element modeling of both an element itself and its behavior under uniaxial tension have been demonstrated with a structural element of flexible woven composites. The main components of the material, such as reinforcing fabric and material's matrix were examined in modeling. The reinforcing fabric is a plain weave. These yarns were taken as an elastic material. The matrix of the material was considered to be a soft polymer with the possible occurrence of irreversible elastic-plastic deformations. Moreover, the possible occurrence of damages in the structure of the material under high loads was taken into account in modeling. The fields of stresses and strains were built; the zones of the material's internal damages under uniaxial tension were demonstrated. The risk zones of weave were revealed.



*Keywords:* Flexible woven composite; Finite element method; Stress–strain field; Damage.

## Introduction

The main models used for describing the structure of woven materials are applicable only to a "hard" composite, with solid polymers, for example, hardened epoxy resin [1–6], acting as fillers. Geometric nonlinearity may be neglected for these materials [5,6], since deformations occurring through loading are not too large. The models created by the Composite Materials Group of KU Leuven (Belgium) have gained a wide recognition [7–11]. This research team carried out comprehensive studies of the behavior of woven composites, starting from the experimental component and up to designing the WiseTex software suite [10] allowing to model the behavior of the materials under consideration based on the full finite element modelling and to visually determine the most critical areas of the reinforcing fabric.

Geometric nonlinearity has a significant effect on the mechanical properties of flexible woven (fabric) composite materials [12,13]. It is related to the type of composite filler and the deformation specifics of reinforcing yarns that straighten out during deformation, change their stiffness [14], transform from a bending state to axial tension and separate from the matrix, which leads to damage and debonding between the fibers and the matrix in the structure of the material.

In order to construct a model of a structural repeated unit cell (called RUC), it is necessary to accurately describe the internal state variables [15]. It follows from the analysis of the geometrical

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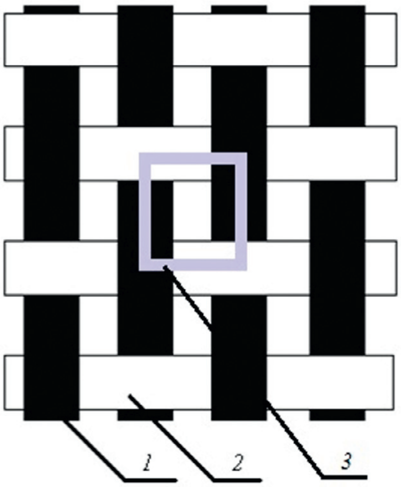


Fig. 1. Plain weave schematic (top view) *1* is warp yarn; *2* is the weft yarn; *3* is the repeated unit cell (RUC).

characteristics of the plain weave in question that the yarn length of the warp and the weft differs from the yarn width by no more than one order of magnitude; it can be concluded, then, that it is necessary to take into account the bending moments in the yarns [15-17]. Additionally, the presence of the bending causes compression areas to emerge in the fabric yarns, which requires using kinematic hardening for describing the potential elastic plastic deformation, as in this case the fabric yarn is considered to be a composite material consisting of flexible fibers and an elastic plastic matrix.

This paper reveals the main features of constructing a deformation model for the repeated unit cell of a flexible woven composite using the finite-element modeling of the behavior of a RUC of a flexible woven composite sample as an example; the most critical areas of the plain weave have been visually determined. We have obtained the stress and strain fields, as well as the areas of the maximum accumulation of internal damages occurring due to debonding in the material structure.

## Repeated unit cell and the specifics of constructing the structural model

Periodic structures allow describing the behavior of the whole material through standard repeated elements of the internal structure. The plain weave under consideration (Fig. 1) has a regular periodic structure in which a repeated unit cell (RUC) can be selected. It is generally assumed that for the materials in question, this cell contains a warp yarn, a weft yarn, and a weave architecture; the customary appearance of a cell is marked by a rectangle in Fig. 1.

Without loss of generality and taking into account the specifics of this type of weave, let us assume that the shape of the weave changes by the same law over the whole fabric area. Let us examine a type of a RUC structure along the warp direction. In the longitudinal cross-section of the RUC (Fig. 2), the reinforcing weave yarn has the shape close to a sine curve; to simplify the modeling of the structure this curve can be approximated by a set of straight-line segments (similar to the method used in Refs. [1,14]).

The elliptical cross-section of the yarns can be approximated by a rectangular shape [12]. The RUC shown in Fig. 3 is the result of isolating a structural element and simplifying the weave geometry; this RUC can describe the behavior of the material as a whole.

A RUC of a flexible woven composite material consists of reinforcing yarns and a filler. The reinforcing yarns (of the warp and the weft) are a unidirectional composite consisting of a yarn matrix (a yarn filler) and reinforcing fibers (tows). For correctly modeling the reinforcing fabric, yarn reinforcement is introduced for each individual linear segment and coincides with the direction of the yarn. Considering the nature of

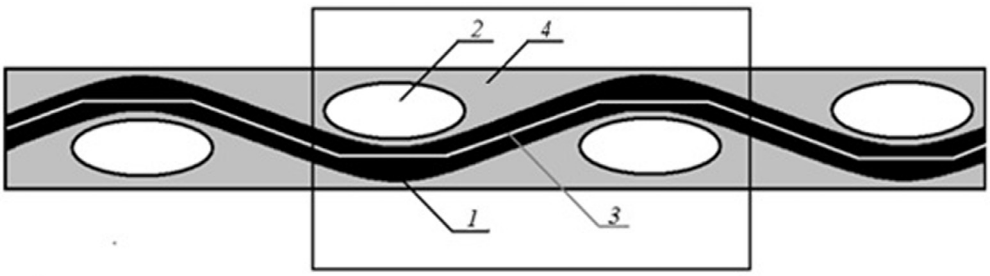


Fig. 2. Longitudinal cross-section oriented along the weft *1* and *2* are the warp and the weft yarns, respectively; *3* is the linear approximation of the sine shape of the warp yarn, *4* is the matrix (filler) of the flexible woven composite.