COMPUTATIONAL MECHANICS 2023
38th conference with international participation
Srní
October 23 - 25, 2023

Compressional behaviour of plain woven fabric

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1. Introduction

Many times in operation, woven fabrics and textile materials, in general, often undergo both transverse and longitudinal compression. How filaments interact with one another during abrasive compression for multifilament yarns can significantly affect their response to those types of loads. Several research articles have performed experimental works on the compressive behaviour of monofilament and multifilament woven fabric [1, 2, 4]. On the other hand, many authors have used empirical and finite element method (FEM) in modelling the behaviour of fabrics in compression [3]. Primarily, the FEM of a unit cell (UC) is investigated in compression; the UC was assumed to be symmetric in both the warp and weft direction. The result of the work was compared with three analytical models. Early empirical works have developed models showing the relationship between applied initial and final compressive force, p_0 and p, respectively, and the fabric's initial and new thicknesses, T and T_0, respectively,

$$p = p_0 \, e^{-\frac{T-T_0}{b}}, \tag{1}$$

$$\log T = \log a - b \log p, \tag{2}$$

$$T = a + \left[\frac{b}{p+p_0}\right], \tag{3}$$

where p_0 is the initial compressive load, T_0 the initial thickness at p_0; and a, b are individual constants derived from experiments. All three equations show the relationship between applied load and thickness; the first equation employs an exponential function (Kawabata et al.), the second equation a logarithmic function (Young et al.) and the third equation, an inversely proportional function (Holmes et al.). However, in recent times, several works have been published on the compressional behaviour of woven fabrics using newer and modified numerical methods and FEM [3]. The Kawabata Evaluation System is now employed in measuring low-stress mechanical properties, including surface properties, friction between yarns, compression, shear, bending and tension.

2. Experimental setup

2.1 Fabric thickness measurement

The experimental method involves first measuring the thickness of the sample. Table 1 below shows the fibre geometrics obtained from a simple laboratory measurement using digital callipers. In literature, there exist a number of techniques for measuring fibre thickness. An example is to place the fabric between two thin plates of known thicknesses. A 100 gf/cm^2 weight (equivalent to 9.8066 kPa) is mounted on the upper plate to give it enough pressure to straighten out creases and crimps in the yarns that make up the fabric, and to capture precisely the thickness of the fabric, and not merely regions with lone yarns. Excessive weight would press the sample below its actual thickness. Fig. 1 shows the laboratory measurement of the sample. Ten samples were cut and measured, and the average was evaluated as 0.38471 mm, using DNV ISO 5084:1996 standards at standard environmental conditions of 20 ± 2 °C and 65 ± 2 % for temperature and humidity, respectively. The calibration is done by zeroing the caliper with the flat stiff metal plate, placing the fabric under the plate, and taking the reading.

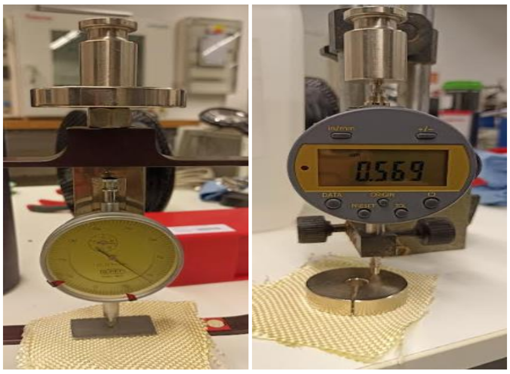

Fig. 1. Fabric thickness measurement setup *(a)* analogue, *(b)* digital

2.2 Compression measurement

The thickness measurement defines the fibre material geometrics when modelling in Texgen (mesoscale) or DFMA - Digital Fabric Mechanics Analyser (microscale). Other physical parameters include yarn width, yarn spacing and height, which play a crucial role in the mechanical behaviour of the yarns and fabric.

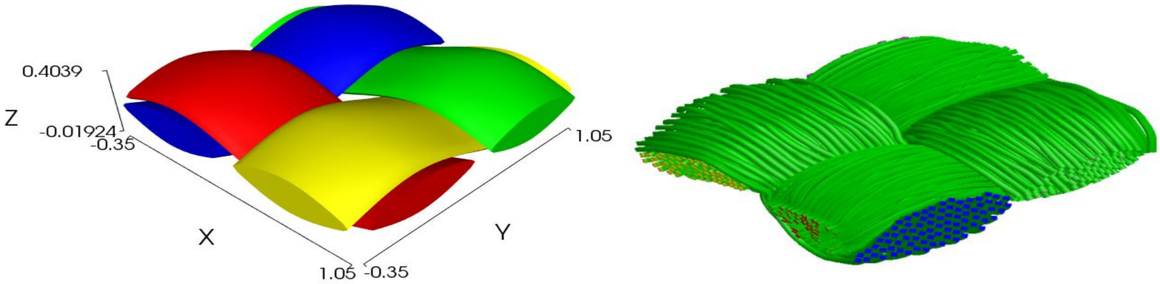

Fig. 2. Fabric model *(a)* TexGen (mesoscale), *(b)* DFMA (microscale)

3. Building the simulation

The simulation was tried in four different software including Abaqus, Ansys – Explicit Dynamics, Comsol Multiphysics – Time-Dependent Analysis and Marc Mentat – Transient Dynamics. The latter provided the most efficient, easiest and most realistic way to model the system. Into Marc, the model is imported as a .step file. The model is assumed to be symmetric to simplify the simulation system requirement. Thus, a double symmetry body is cut from the full model, so only a quarter of the whole model is used, as shown in Fig. 3. The idea is to perform a compression of up to 75 % of the fabric thickness. The faces A and B are constrained for translation in their respective lateral direction because these are the planes of symmetry of the model. The material properties are set as structural steel for the compression plate and the bottom sheet metal, whereas the material for the yarn is specified in previous experiments. The element size is set at 0.018396 mm. The model comprises four bodies and three contact regions: the yarn-to-yarn bonded breakable contact, the frictionless contact with the lower yarn and the bottom metal sheet. The model is compressed up to 70 % of its original fabric thickness, so the compression depth is 0.3983 mm. To reach the area of plastic deformation of the yarn will involve providing plastic data, which was not available at the time of the simulation; this helped inform the decision to limit the simulation to the region of linear deformation. Two symmetry boundary conditions are created to account for the two symmetry planes in the *x* and *y* axes. The displacement load is chosen over velocity because it is more precise regarding the compression level, and it more realistically captures the slow time step of a compression process against impact simulation that requires only a few microseconds. It is essential to set the compression plate as a rigid, undeformable block and the flat bottom plate be constrained at the ground side and have a bonded (glued) interaction with the lower yarn.

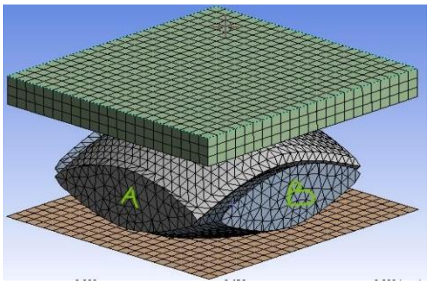

Fig. 3. Dual symmetry model mesh

4. Results and discussion

The simulation is run with results for 50 steps. The output number 3004 in Marc indicates a good convergence with no errors in the simulation. Fig. 4 below shows the initial and final compression positions.

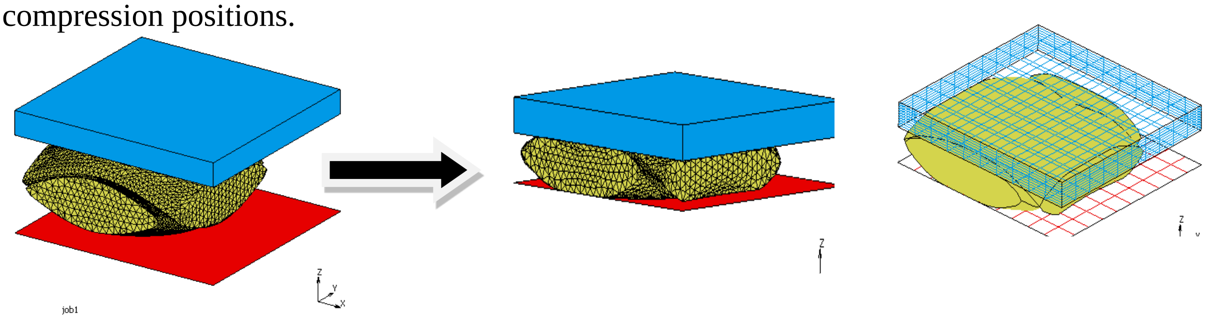

Fig. 4. Deformed and undeformed model

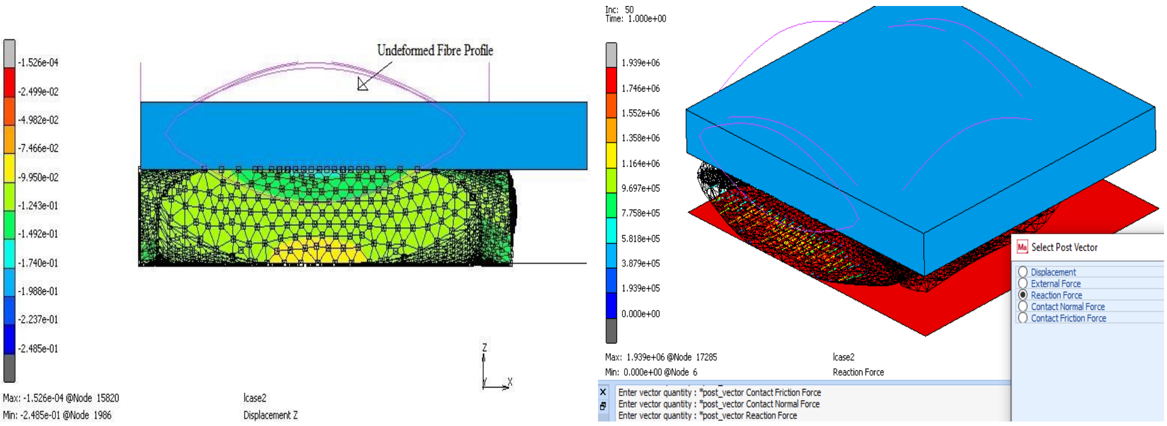

Fig. 5. Contour plots of deformed and undeformed model

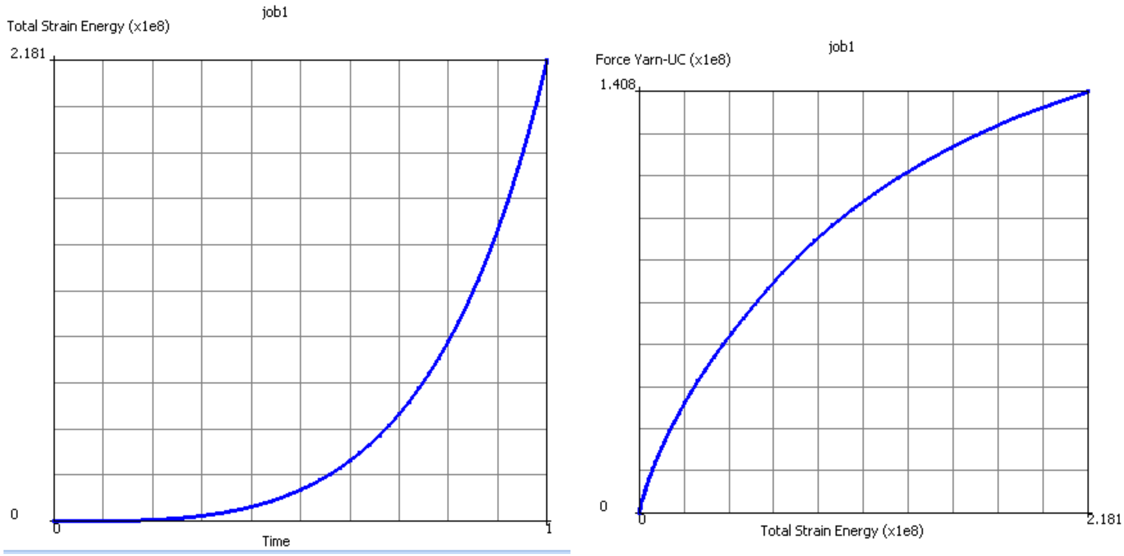

Fig. 6. Strain energy, time and total applied force by displacement

Fig. 5 shows the contour plot of the global displacement in the *z*-direction. The negative sign depicts the reverse direction, and the undeformed profile is switched on to appreciate the compression action further. For the vectors deliverables, the global displacement, reaction force, contact normal force and contact frictional force. Fig. 6 captures the plots of strain energy versus time and then force. The strain energy depicts a combination of energies arising from such entities as tension, compression and bending in a given unit cell. Further work will involve analytical models.

Acknowledgement

This publication was written at the Technical University of Liberec as part of the “Research of advanced materials”, SGS-2022-5072 project.

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