

COMPUTER SIMULATIONS OF PAPER STRENGTH

Prepared contribution

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Abstract

We study the strength of paper using computer simulations. Our model is a stressed mechanical 2D random fibre network (RFN), the equilibrium of which is computed using a commercial FEM (Finite Element Method) solver Abaqus. The novelty in our approach lies in more detailed introduction of mechanical properties of fibres and bonds into the mechanical model, enabling the study of effects of microscopic (fibre/bond – level) properties on relations between macroprocessor properties.

The mechanical properties of fibres and bonds are defined by Young's modulus (or moduli in anisotropic case) and stress-displacement curve. In our video presentation, fibres are purely elastic whereas bonds are elastic-plastic. The video shows the behaviour of network being stressed by forcing increasing displacement on one boundary.

1 Network generator

A RFN is generated by placing fibres onto a plane randomly or according to a chosen probability distribution. The density of network can be varied from percolation threshold (q_c) up to more than $4q_c$. Bonds are formed at crossing points of fibres. The

unconnected ends of fibres are moved in order to reduce the number of elements to be calculated.

2 Bonds between fibres

In order to achieve more realistic description of elements in the computer model, we modelled the behaviour of a single bond consisting of hydrogen bonds. The modelling was based on the following idealised picture of the bonding area:

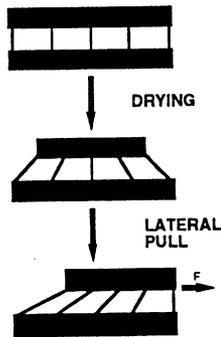


Figure 1: A simple model of the behaviour of a bond between two fibres during drying and lateral stressing. The upper fibre is perpendicular to the plane of paper and the length axis of the lower one stretches from left to right. The fibres are connected by hydrogen bonds.

In the model, the bonding area is unstressed before drying. In contracting laterally during drying, the upper fibre introduces stresses into the hydrogen bonds connecting the fibres and into the bonding areas of both fibres. The modelled bonding area is stressed by applying force to the upper fibre in the plane of the

bonding area or perpendicular to it. Below is an example of the results.

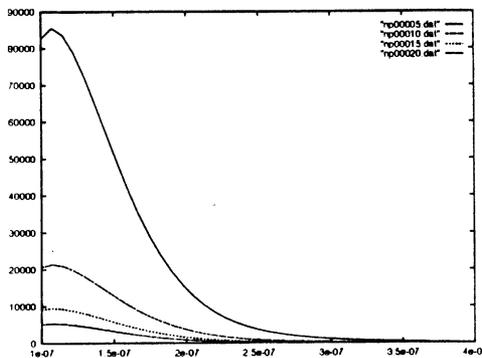


Figure 2: A plot showing the results of a perpendicular stressing of a bonding area with Lippincott-Schroeder-type bonds for various degrees of contraction. The stress and displacement scales are arbitrary [1,2].

In the computer model, the results are employed in the stress-strain definitions of finite elements.

3 Stimulations

Once a RFN is created, it is mapped into finite elements (FE). For each fibre segment a bond element is assigned, and bonding areas are implemented according to the following picture:

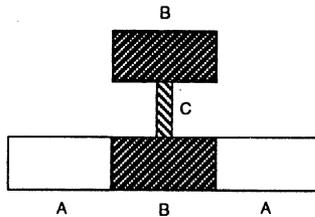


Figure 3: The fibres are oriented in the same way as in figure 1. The element A is a normal fibre material, element B is the compressed part of fibre and C is the bonding element. The results acquired in the modelling of the bonding area are fed into the stress-strain curves of elements B and C.

In the same way, the stress-strain behaviour of the fibres can be defined. The model allows distributions for material parameters for elements. For example, the Young moduli of fibres or the elastic→ plastic behaviour limits for bonds can be assigned for a single element according to a Gaussian distribution.

The model is fed into a standard commercial FEM solver (Abaqus). During an Abaqus run a network is stressed by applying tension to the ends, and the stressing is carried out in a sequence of mechanical equilibrium states. Geometrical and stress status information can be extracted from each state. The evolution of the physical state of the system can be traced by analysing stress-strain curves (an example of which is in Figure 4) and the change of stress distributions during loading.

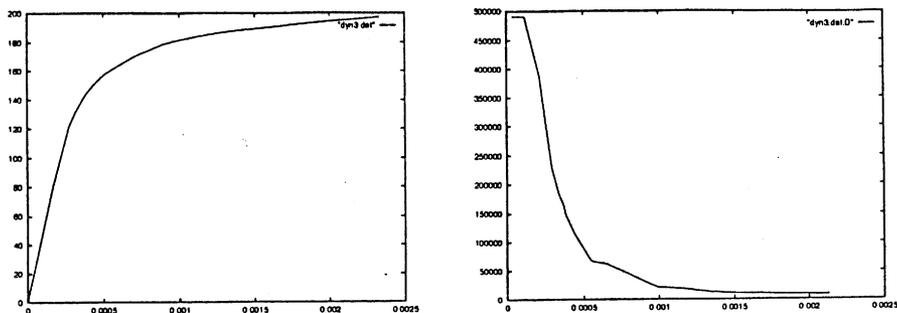


Figure 4: The left-hand figure is a stress-strain curve for a network with elastic fibres and elastic-plastic non-breaking bonds. The right and figure is the derivative of the left hand curve and shows the rapid weakening of the axial (Young's) modulus of the network.

The model is being run on a Convex C3840 supercomputer in CSC. A 600-fibre network of area 10×10 fibre lengths may require several CPU hours to run, depending on material parameters. As high-power workstations are available nowadays, the model can be run on desktop as well. The CPU time consumption scales roughly as square of the density, so a computer achieving half of the computer power of a C3840 runs a problem of same density but half the size in the same time. (Alternatively, 70% of the density and same size yields the same effect.)

Prof H Kropholler, UMIST, UK

On your random network are you using the Dodson 1971 model and secondly what kind of computer power are you using for doing the simulations.

V Ralsanen

The model is our own and the required computer power is pretty high.