CHAPTER 2

THEORY

2.1 Anisotropy

As the fibres in a machine-made paper are more strongly oriented in the machine direction than in the cross direction, the paper has different properties in different directions. This is anisotropy. A diagram showing, for example, the breaking length measured in different directions, is given in fig. 4. The tear strength, on the other hand, is highest when tearing across the machine direction.

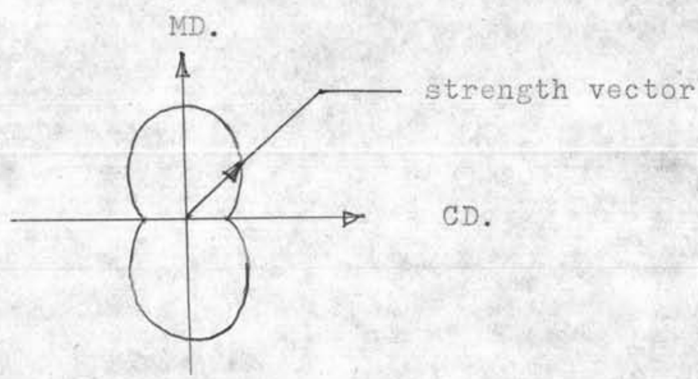

FIG. 4 The breaking length of paper in different directio directions.

It is, however, an empirical fact that, as long as the ultimate strains do not differ too much, the product of values measured in the machine and cross directions respectively is reasonable constant. Theories for the influence of anisotropy on paper properties, based on simplified models where all fibres are assumed to lie in the same plane ("random sheets"), have been developed by Van den Akker in the USA, Corte and Kallmes in England and Page in Canada.

a paper can at the most reach 1/3 of the tensile strength of the individual fibres, assuming that these are randomly orientated. In practice, the highest recorded tensile strengths are abount 1/4 of that of the component fibres.

Paper consists of fibres bound together in a network. On the average each fibre is tightly bound to 20-40 other fibres per millimeter of its length. These fibre bonds each have a shear strength of abount 1 pond. The strength of the actual fibres is abount 2-10 pond. At the moment of rupture, a considerable number of the fibres are torn apart, while others are pulled out from the network. The stronger the paper, the more fibres are torn apart.

The fibre bonds consist mainly of hydrogen bonds between the cellulose molecules. The strength of a sheet of paper decreases with increasing moisture content, due to the fact that moisture reduces the strength of the hydrogen bonds. The strength of individual fibres, however, increases with increasing moisture content. At higher moisture contents the fibres are more plastic, so that stress concentrations at non-uniformities in the fibre wall structure can be more easily evened out.

A fibre in a sheet which is subjected to a stress transmits force via the inter-fibre bonds to other fibres in its vicinity. A paper strip subjected to a tensile test contains a zone where rupture will occur, through which a large number of fibres pass as shown in fig. 5. One of these fibres and the bond which connect it to other fibres are shown in fig. 6. It is assumed that the paper density is not excessive, so that the fibre is not bonded along the whole of its surface.

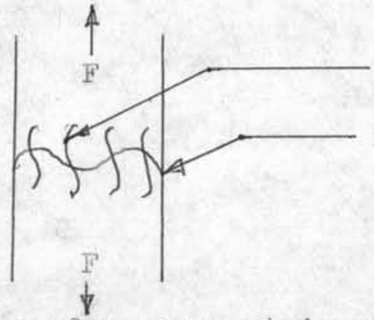

FIG. 5 A rupture zone of a paper strip subjected to a tensile test passes through a large number of fibres.

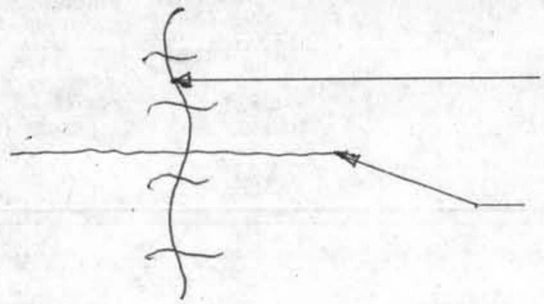

FIG. 6 One of the fibres which a rupture zone passes through and the bond which connect it to other fibres.

In the initial phase of a tensile test, the paper is elongated fairly evenly over its whole surface, which means that the fibre studied is also elongated fairly evenly. The stresses in the fibre reach a low but even level, fig. 7, curve 1. Forces are transmitted to the fibre via fibre bonds in such a way that the fibre receives a stress contribution from each bond, counted from the ends to the middle. The contribution may be positive or negative.

When the paper is extended further, all of the fibre bonds contribute to a higher tensile stress in the fibre. The tensile stress is thus greatest in the middle and least at the ends of the fibre. See fig. 7, curve 2. If the elongation of the paper were distributed so that the tensile stress was large at the ends of the fibre, the load on the outermost bonds would be so high that they would break. The fibre will therefore normally have zero stress at the ends, increasing linearly to a maximum stress at the middle of the fibre. Due to this successive fracture of certain inter-fibre bonds, a reduced number of active fibres, which are loaded to breaking point, remains at the moment of rupture. These are torn apart at the moment of rupture, while the other fibres are pulled out from the network.

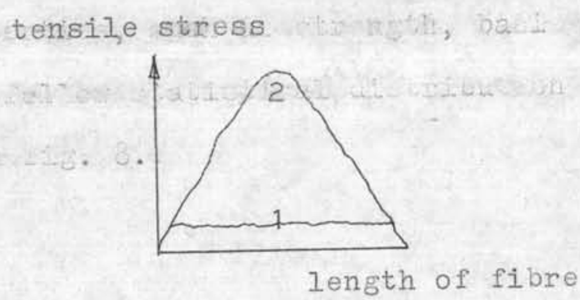

FIG. 7 Stress in the fibre under a tensile test.

2.3 Statistical Distribution of Paper Properties

All paper properties, such as strength, basis weight and thickness, to name a few, follow statistical distribution functions of the general form shown in fig. 8.

Curve A shows the (exaggerated) variation in, for example, breaking length for a paper of uneven structure, while curve B shows the variation in breaking length for a well-formed paper made from the same furnish. The latter contains fewer weak zones which can cause rupture at low stresses. Even papers are stronger than uneven papers.

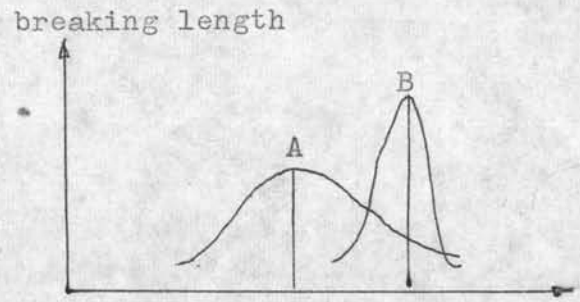

FIG. 8 The variations in breaking length for a paper of uneven structure and a well formed paper.