FIBRE AND FIBRE NETWORK BEHAVIOUR IN STRAINED WET WEBS

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ABSTRACT

The behaviour of radiata pine (**Pinus radiata** D. Don) latewood fibres and latewood fibre networks in unstrained, strained, and ruptured wet webs at 22 to 32% solids were examined using light microscopy and scanning and transmission electron microscopy. Visible changes with pulp beating and web straining were examined with reference to fibre morphology, fibre collapse, fibre fibrillation, fibre orientation, and web consolidation.

Extensively kinked and twisted unbeaten latewood fibres were irreversibly straightened in a strained wet web. Beating treatments fibrillated fibre surfaces and produced fines which formed interfibre fibrillar networks in wet webs. These fibrillar networks were progressively disrupted as wet webs were strained to rupture. Disrupted fibrillar material aggregated about individual fibre surfaces.

INTRODUCTION

The wet strength of paper webs is an important parameter in the papermaking process. Pulps can have good dry paper properties but poor wet-web strengths (Kibblewhite *et al.,* 1975). Inadequate pulp wet strength can initiate web breaks on paper machines and cause significant losses in paper production.

This paper describes microscopic techniques which illustrate fibre behaviour in wet webs prepared from unbeaten and beaten radiata pine (*Pinus radiata* D. Don) kraft pulps when unstrained, partly strained, and strained to the point of rupture. The techniques allow effects of fibre morphology, entanglement, and fibrillation on wet web behaviour to be examined visually. Preceding papers describe effects of beating and wood quality on the dry paper properties (Kibblewhite, 1973a) and the wet web strength (Kibblewhite, 1975) of pulps examined in the present study.

EXPERIMENTAL

A latewood kraft pulp was prepared from the outer 10 of 30 growth layers in roundwood billets taken from two 44-year-old radiata pine trees. The pulp contained thick-walled fibres (4.0 μm) with a mean length of 3.2 mm and a mean diameter of about 31.5 μm. The number of fibres per gram of pulp was about 5×10^5 (Kibblewhite, 1973a). Pulps were processed in a PFI mill for 15,000 and 55,000 revolutions at 10% stock concentrations, using procedures described previously (Kibblewhite, 1972).

Wet strips were formed in a British standard sheet machine with a metal frame placed on the wire, which gave two strips (25 × 135 mm) from each web formed. Webs at 22 to 32% solids were obtained using conventional sheet couching procedures. Couched strips were peeled from the couch blotters and stored side by side between glass plates. Under these conditions strip moisture contents remained constant for several hours.

Wet strips were strained in a table model Instron tester with a jaw separation of 90 mm and an extension rate of 10 mm/min. Webs were strained to rupture and strained portions of the wet strips were clamped between the jaws of modified Quickfit clamps. Both the clamp and the clamped portion of the strip were moved from the Instron and submerged in liquid nitrogen (−196°C). This procedure was followed as quickly as possible after web rupture to minimise web relaxation before rapid freezing in liquid nitrogen. A similar procedure was followed for webs which were partly strained (i.e., only 60% of the rupture stress applied). Unstrained webs were put into the Quickfit clamp before being submerged in liquid nitrogen. Frozen strips were subsequently cut into rectangular samples for examination using light microscopy and scanning and transmission electron microscopy. One pair of sample edges was cut parallel to the direction of the strain. Samples were freeze-dried and prepared for scanning and transmission electron microscopy by methods described previously (Kibblewhite, 1972). Metal- and/or carbon-coated samples were examined under a Bausch and Lomb Stereozoom 7 microscope with the integrated camera system 11 attachment. Coating of the samples was necessary to confine light-scattering to web surfaces. Samples were examined using reflected light at angles perpendicular and parallel to the direction of strain. It is likely that network configurations changed to some degree when tension was released, as ice sublimed from strained strips.

RESULTS AND DISCUSSION

Unbeaten Pulps

The unbeaten thick-walled fibres formed an uncompacted web (Fig. 1a). Fibres in the unstrained web were extensively twisted and kinked, were not collapsed, and were essentially unfibrillated (Fig. 1a). The effect of applying 60% of the stress required to rupture the network was to straighten but not to collapse the thick-walled fibres (Fig. 1b). Fibres in ruptured webs remained straight after the applied stress was released (Fig. 1c). The unbeaten pulp produced very open strained networks without visible fibre orientation (Fig. 1b). Interfibre and interfibral frictional forces were apparently minimal in the strained web with the result that unbeaten fibres were easily pulled from the network.

Beaten Pulps

Beating is known to make stiff fibres flexible, kinked and twisted fibres straight, and to cause smooth fibres to fibrillate by progressively stripping lamellae from their surfaces (Kibblewhite, 1972; 1975). Consequently, the straight-fibred, fibrillated, and consolidated wet web networks that developed with beating in this study were to be expected. Beaten fibres appeared to be only slightly more collapsed than unbeaten material (Figs. 1a, 2a).

Fibre and network behaviour during the straining of wet webs containing beaten fibres was as follows:

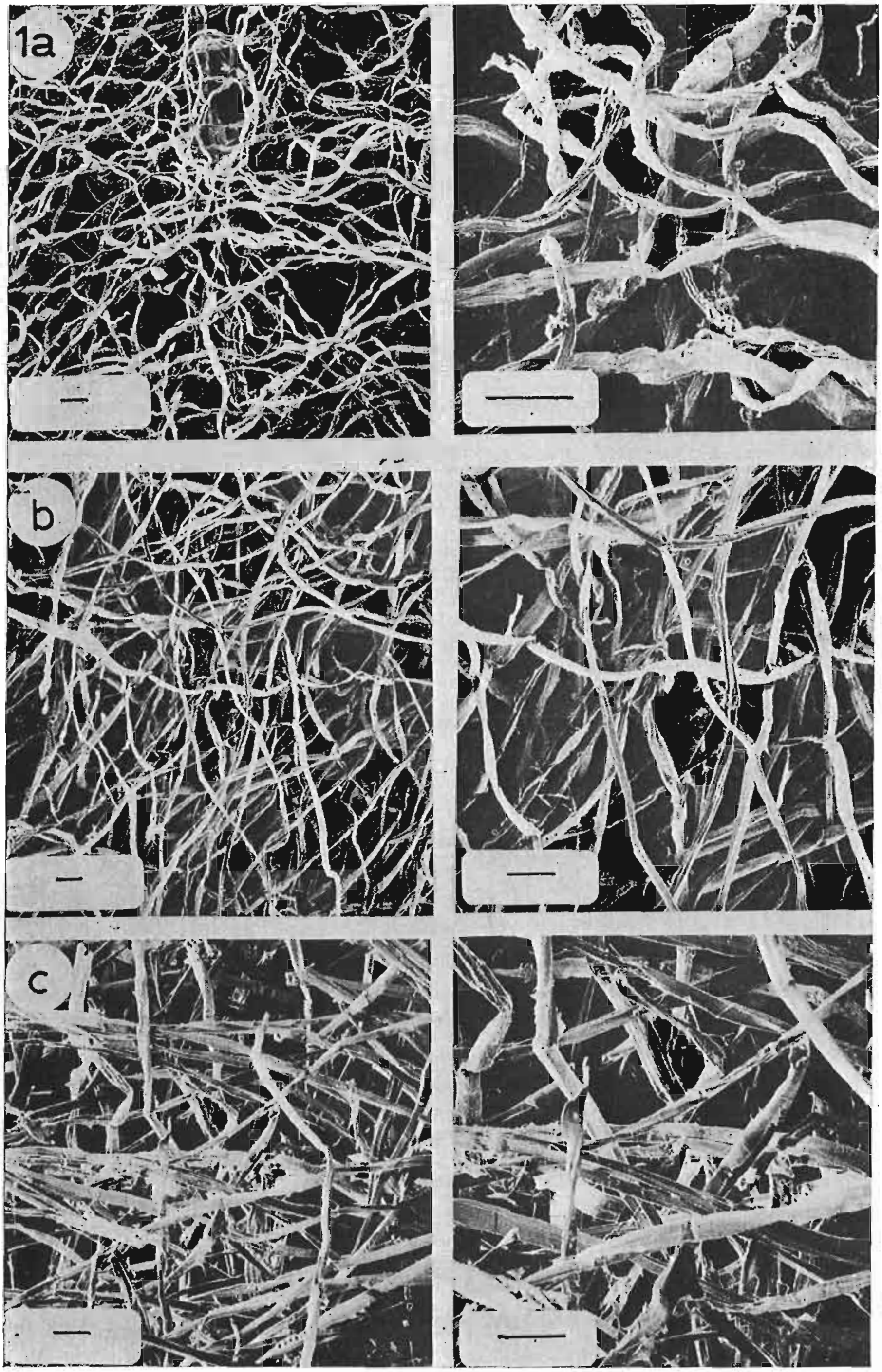

FIG. 1—Surface views of unbeaten latewood fibres in wet webs at 31.2% solids. Scale is 100 μm.
(a) unstrained (b) partly strained (c) strained to rupture

1. Degrees of fibre straightness and collapse were not visibly changed by web straining, as had been found for unbeaten fibres.

2. Interfibre fibrillar networks were disrupted as wet webs were strained to rupture (Fig. 2). Fibrillar remnants in ruptured webs aggregated about individual fibres (Fig. 2b). In webs strained by 60% of their rupture stress, fibrillar network disruption occurred to degrees intermediate between those shown in Fig. 2.

3. Fibre orientation was unchanged visually in webs strained by 60% of their rupture stress (Kibblewhite, 1973b). In webs strained to rupture, only those fibres within or near the rupture zone were visibly orientated in the direction of strain.

4. Rupture appeared to occur by interfibre slippage (as expected) rather than by interfibre fracture (Kibblewhite, 1973b).

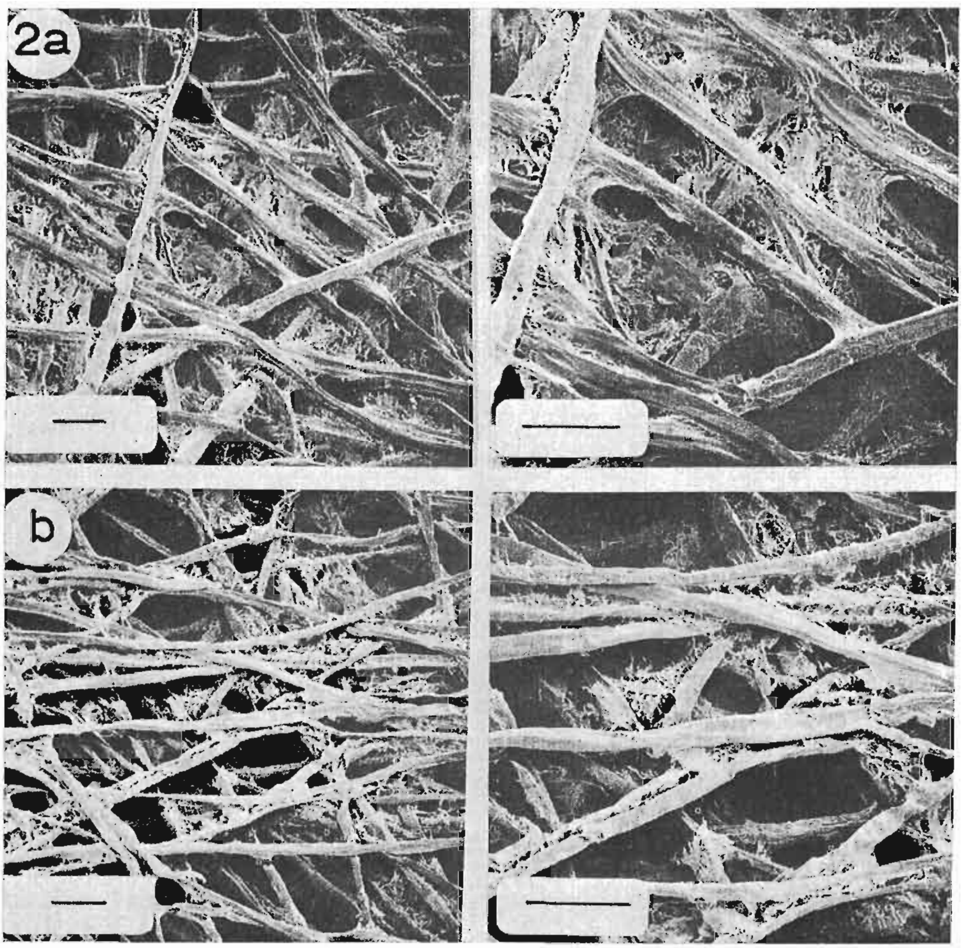

FIG. 2—Surface views of beaten (15,000 rev) latewood fibres in wet webs at 23.1% solids. Scale is 100 μm.
(a) unstrained (b) strained to rupture

Heavily Beaten Pulps

Fibres appeared straight, collapsed, and extensively fibrillated in the consolidated wet webs prepared from the heavily beaten latewood pulp (Figs. 3, 4). Fibrillation and fines were abundant and appeared to control the behaviour of strained wet webs. This conclusion agrees with wet web strength data presented elsewhere (Kibblewhite, 1975). Fibres in webs strained by 60% of the network rupture stress were orientated in the direction of the strain (Fig. 3b). Degrees of fibre orientation and the development of web ripples parallel to the direction of strain increased with increasing strain (Fig. 3c). Rupture appeared to occur by interfibre and interfibril slippage (as expected) rather than by fibre fracture (Fig. 3d). Orientation was particularly evident in this heavily beaten pulp because the extensive fibrillar networks became orientated but remained entangled, and fibrils did not become visibly separated from one another when the web was strained (Fig. 4b). The large amount of fibrillar material apparently allowed extensive fibre and fibril slippage and re-orientation without fibrillar network disruption in wet webs under strain (Figs. 3, 4).

CONCLUSIONS

1. Twisted and kinked unbeaten latewood fibres were irreversibly straightened in a strained wet web.

2. Unbeaten latewood fibres formed an uncompacted mat and were not collapsed in unstrained, strained, or ruptured wet webs.

3. Beating caused fibres to fibrillate and produced fines which formed interfibre fibrillar networks. These were progressively disrupted with straining and the disrupted material aggregated about individual fibre surfaces. Fibrillar networks are orientated but remained intact in strained wetwebs prepared from heavily beaten and fibrillated latewood fibres.

4. Fibres are only visibly orientated in partly strained wet webs formed from heavily beaten and fibrillated latewood pulp.

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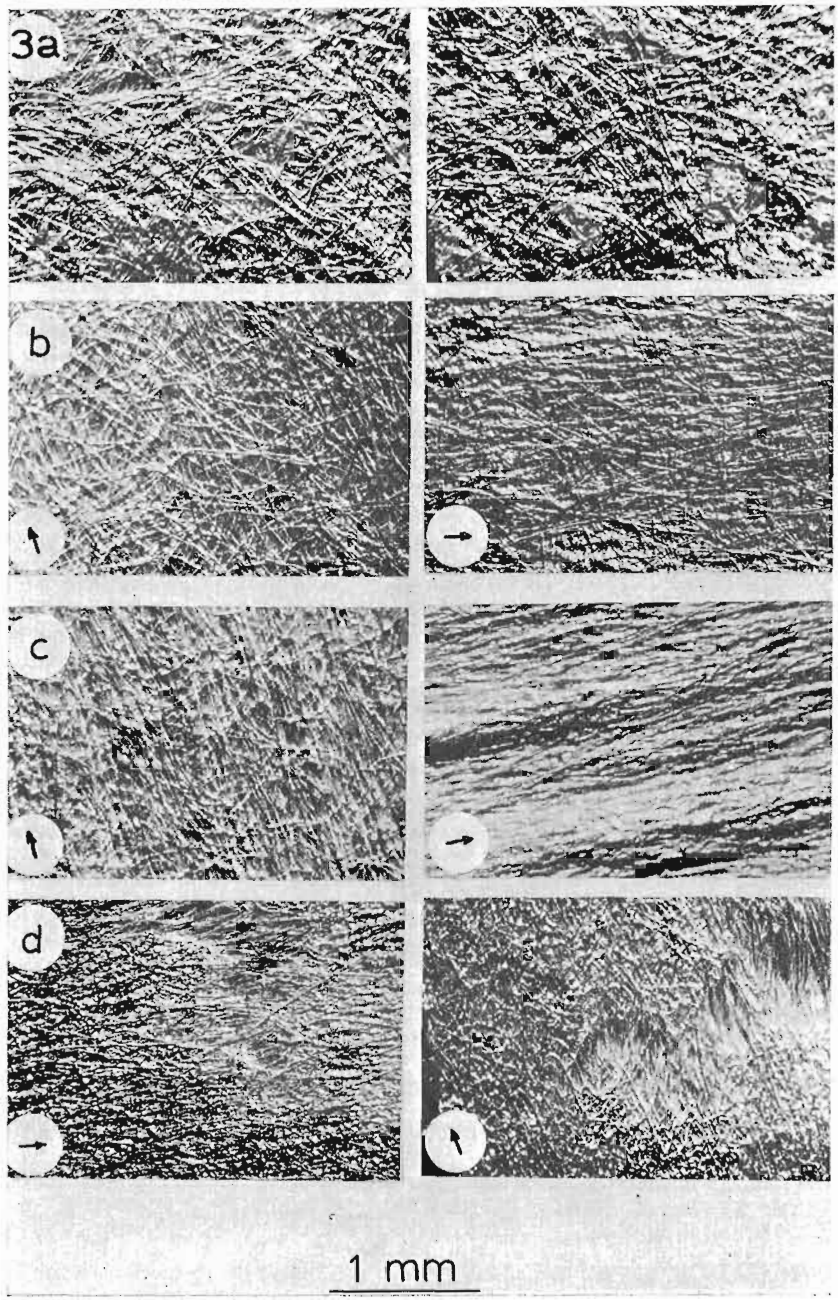

FIG. 3—Surface views of heavily beaten (55,000 rev) latewood fibres in wet webs at 22.7% solids. Micrograph pairs show a specimen under reflected light orientated parallel to, and perpendicular to, the direction of strain. Arrows indicate direction of web straining.
(a) unstrained (b) partly strained (c) strained to rupture
(d) strained to rupture — zone of rupture

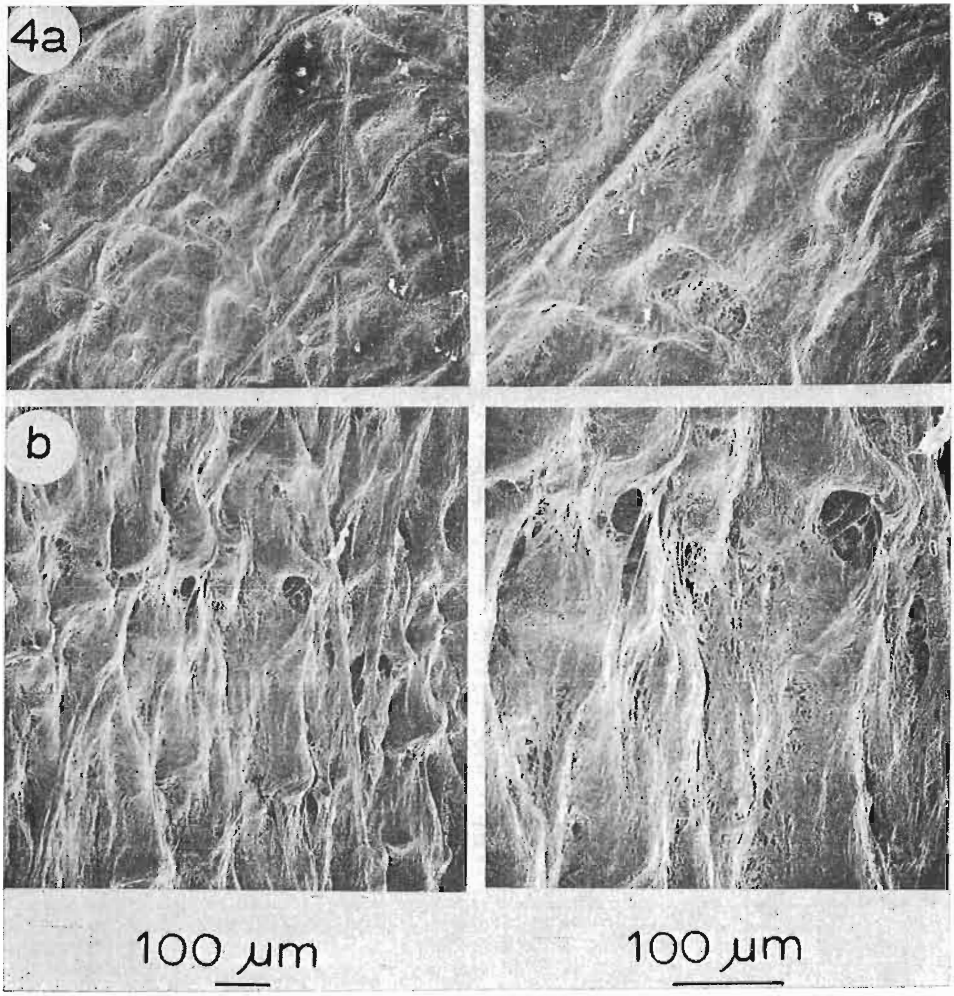

FIG. 4—Surface views of heavily beaten (55,000 rev) latewood fibres in wet webs at 22.7% solids.
(a) unstrained (b) strained to rupture

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