Insights on the refining mechanism

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ABSTRACT: For this study, we examined fiber aggregates from inside a refiner and those from the refiner discharge using a microscope to determine their morphological and structural characteristics. Our observations indicate that a rolling mode refining prevails in thermomechanical chip refining. We noted that fibers are refined in a rolling mode but not an along-the-fiber-axis mode as previously reported by other researchers.

Application: This research advances the understanding of chip refining and may help improve refiner plate efficiency.

Mechanical pulps are produced by two processes: wood grinding and chip refining. In grinding, the logs are pressed against a rotating pulpstone whose protruding grits peel the fibers off the log surface, producing fibrous particles of various forms and sizes. In disc refining, the chips are basically shredded between two refiner plates with bars and grooves—at least one of which is rotating—to make a papermaking pulp. The fundamental difference between the two processes is that the raw material used in grinding is immobilized while that used in refining is not. Between the two processes, refiner mechanical pulping is the most important in terms of global production capacity.

How fibers are refined in a disc refiner is of great importance, both for refiner plate design and pulp quality improvement. Researchers (1-3) had used high-speed photography to detect fiber movement in a refiner and reported that refining takes place along the fiber length. However, a recent study (4) on the morphological characteristics of fiber aggregates collected at the discharge of a pressurized refiner indicated that most of the fibers were rolled into strand-like aggregates in which most of them were aligned approximately in the same direction. This latter finding suggests that a predominant rolling mode (across-the-fiber) mechanism prevails in refining. The purpose of this study was to further elucidate the mechanism of chip refining through microscopic examinations of fiber aggregates collected within a refiner and at the refiner discharge.

EXPERIMENTAL

We used a Sunds Defibrator CD300 pilot unit to produce a thermomechanical pulp (TMP) from black spruce chips. The characteristics of the refiner plates used were previously reported (4). In the process, chips were first washed and atmospherically presteamed for 10 min and then screw-fed (2:1 compression ratio) into the digester where they remained for 5 min at 126° C before being refined at that temperature. The plate gap was set at 0.5 mm for both the flat and conical segments. The discharge consistency was about 22%. When the refining conditions were stabilized, a sample of about 500 g (CSF about 250 ml) was collected from the blow cyclone. Afterwards, the feeding of chip was stopped and the motor stalled, simultaneously. The refiner was allowed to cool before the casing was opened for observation and sampling. The discharged pulp and that from the inside of the refiner were examined using a stereomicroscope equipped with a camera (Wild Heerbrugg TYP352873).

RESULTS AND DISCUSSION

Screw-pressed chip

As shown in **Fig. 1**, chips collected from the feed-screw exit (entrance to the disc chamber) were extensively destructured, presumably by the plug screw. The material was in fact rather heterogeneous, physically. Some became to some extent a fibrous mass while others remained relatively intact, structurally.

Pulp from breaker-bar zone

Figures 2 and 3 show the general characteristics of the pulp collected from the breaker-bar zone. The coarse pulp consisted of aggregates seemingly aligning in an ordered parallel arrangement. A closer look at these aggregates (**Figs. 4 and 5**) indicated that they usually had a central core of parallel bundles being wrapped transversely by finer fiber elements. **Figure 6** shows the entanglement of fine elements with a coarse bundle.

The morphological and structural natures of these aggregates indicated they have a preferential orientation, presumably parallel to the breaker-bars.

Pulp on breaker-bars

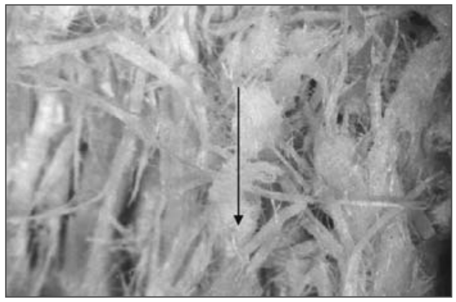
Figures 7 and 8 clearly show that the fibers on the surface of the pulp anchored onto the refiner bars were aligned tangentially—in the direction of rotation of the refiner disc. This would be the picture when a high-speed camera is used for observation. However, this fiber distribution pattern on the plate surface could be deceptive. Surprisingly, the inside view (**Fig. 9**) and the bottom view (**Fig. 10**) of an aggregate anchored onto the breaker-bars indicate unmistakably that the majority of the fibers were radially aligned, perpendicular to the direction of rotation.

This finding suggests the possibility of a preferential axial orientation of fibers towards the disc periphery, confirming the probability of a rolling mode refining as suggested in an earlier work (4). Regarding the tangentially oriented fibers on the bar surface, they are aligned by the shear action of the rotor bridging them across the bars.

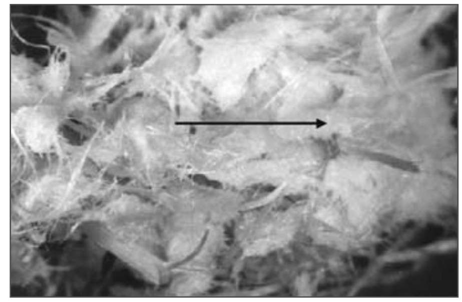
Pulp from refining zone

Microscopic examination of aggregates collected from the plate surface in the refining zone reveals similar pattern of fiber orientation, as in the breaker-bar zone (**Figs. 11-13**). The aggregates located in the grooves in the refining segment also unequivocally indicates a preferential radial orientation of fibers in the refiner. Conversely, if all the fibers travel with their long axis in the direction of disc rotation, those deposited in the grooves would have coiled under the shear force exerted by the bars, instead of being aligned parallel to the bars. In reality, this coiling effect does not prevail.

1.Chips from the feed-screw entering the refiner chamber. They are physically heterogeneous (0.4X)



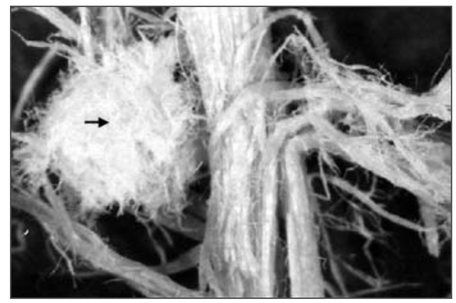
2. Ordered alignment (arrow) of strand-like aggregates from breaker-bar segment near refining zone (4X)



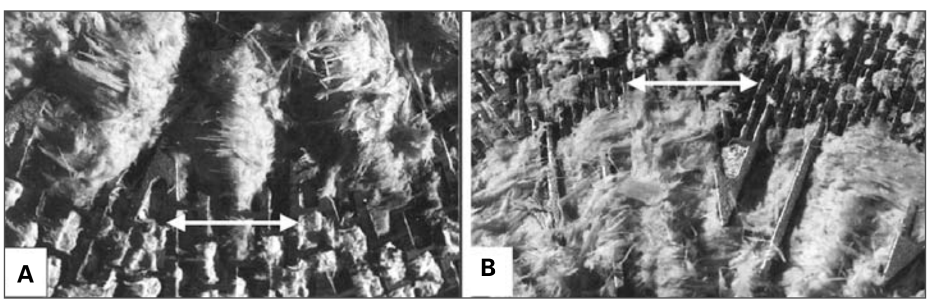
3. Pulp from breaker-bar segment near refining zone. The aggregates have an ordered alignment (arrow) (4X).

4. A rope-like strand of fiber bundles enwrapped with defiberated elements collected from breaker-bar segment near refining zone (4X)

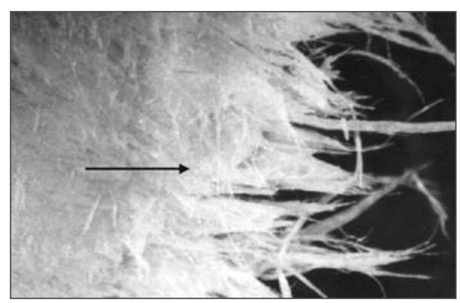
5. A strand-like aggregate consisting of fibers and fiber bundles enwrapped with fiber elements collected from breaker-bar segment near refining zone (6X)



6. Entanglement of a spherical aggregate (arrow) of well defibrated elements with a large partially defibrated bundle from breaker-bar segment near refining zone (4X)



7. Tangential alignment (arrow) of fibers on refiner plate surface. A: stator; B: rotor (0.2X).



8. Surface view of a fiber mass anchored onto a breaker-bar. The fibers are oriented in the direction of the rotation (arrow) (4X).

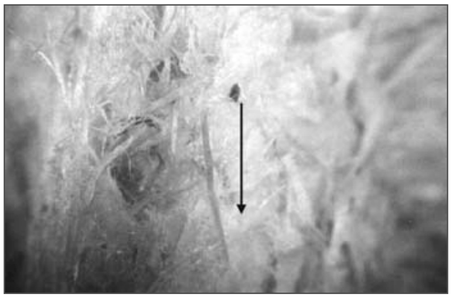
Pulp from discharge

The aggregates of the pulp collected from the refiner discharge can be arbitrarily divided into two groups, strand-like and spherical. The strand-like aggregates, representing about 80% of the total pulp mass, had a core usually made up with long fibers or bundles, as **Figs. 14-15** show. Fine particles or fibers were found wrapped around the aggregate's long axis. Large strand-like aggregates could be formed by entanglement with smaller ones, spherical or strand-like (**Fig. 16**).

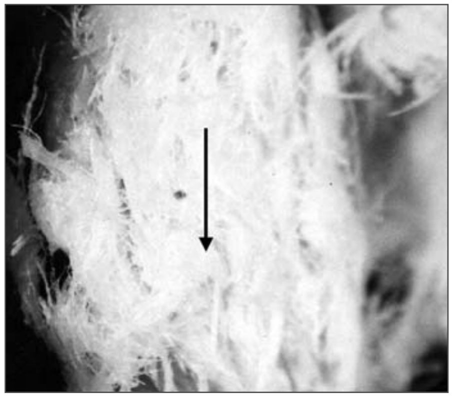
On microscopic examination, a spherical aggregate appeared as a tightly woven cotton ball (**Fig. 17**).The spherical aggregate could be entangled with a strand-line aggregate (**Fig. 18**) or with another spherical one (**Fig. 19**).The fibers on the surface of a spherical aggregate seemed to orient themselves randomly (Fig. 19) while those on the surface of oval aggregates (Figs. 20 and 21) appeared more or less perpendicular to the longer axis of the aggregates. However, the majority of fibers inside an oval aggregate aligned principally in the long axis (**Fig. 20**). The aggregate is in fact made up with numerous tiny strand-like aggregates, as shown in **Fig. 21**.

REFINING MECHANISM

The morphological and structural characteristics of the aggregates of a thermomechanical pulp discussed above indicate a preferential radial orientation of fibers and a rolling mode refining. The

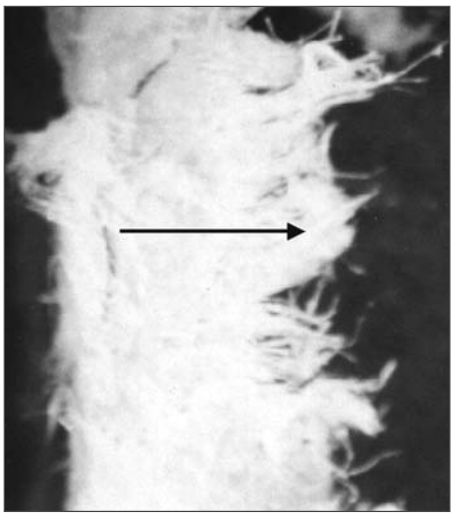


9. Inside view of the aggregate shown in Fig. 8. The fibers are aligned parallel to the breaker-bar (arrow) (4X).

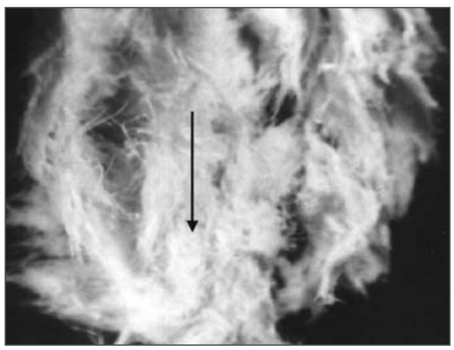


10. Bottom view of the aggregate shown in Fig. 8. The fibers are aligned parallel to the breaker-bar (arrow) (4X).

11. Fibers on the bar surface of the conical segment are aligned in the direction of rotation (arrow) (about 0.4X)

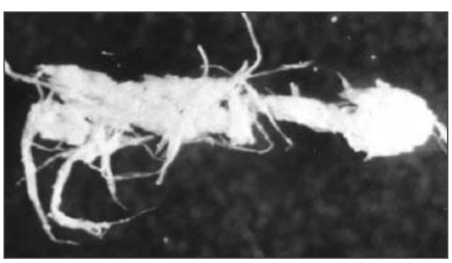


12. Surface view of an aggregate from the groove in refining zone. Surface fibers are aligned in the direction of the rotation (arrow) (4X).

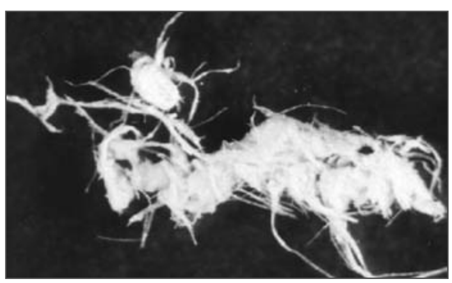


13.Inside view of the aggregate shown in Fig, 12. The fibers are aligned parallel to the breaker-bar (arrow) (4X).

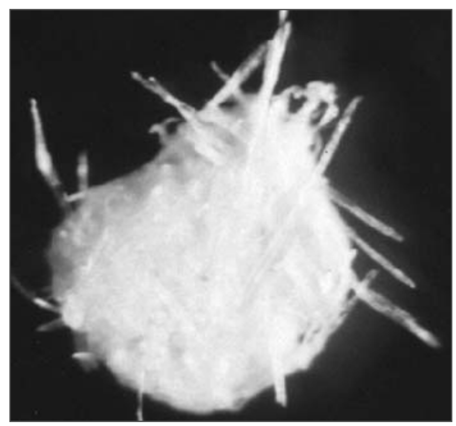
14. A single-fiber aggregate from the refiner discharge. The fiber is sporadically enwrapped with fines (arrows) (40X).



15. A strand-like aggregate form with tiny component aggregates in the discharged pulp (15X)



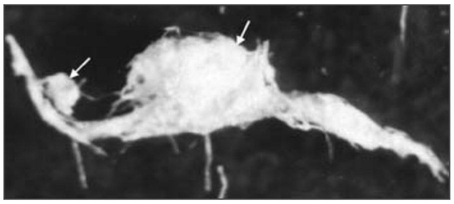
16. A large strand-like aggregate formed through entanglement of aggregates of various shapes in the discharged pulp (10X)



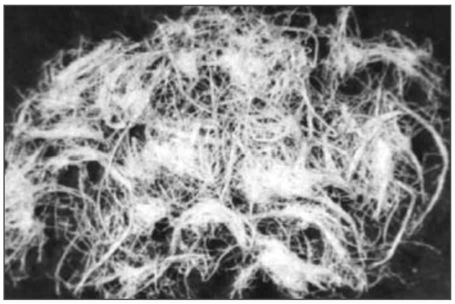
17. A spherical aggregate from discharge pulp. It has a cotton-ball structure (20X).

orientation of fibers in the refiner is controlled by two major forces, centrifugal and shear. Based on the microscopic evidences, the centrifugal force combined with the steam flow in the refiner is believed to be the prevailing factor. It is also believed that the fibers in immediate contact with the bar surface are aligned in the direction of rotation due to the shear action.

With a rolling mode refining, the fibers deposited in the grooves are momentarily lifted out of the grooves, as shown in **Figs. 22 and 23**, and rolled across their long axis by the bars. In the process, the tangentially oriented fibers on the bar surface wrap around those aligned parallel to the bar, with the assistance of the shear force. In this manner, strand-like aggregates are likely to form. Spherical aggregates are believed to form with tiny strand-like aggregates that are rolled into a round shape between the bars. However, the latter is found to represent a relatively small proportion of the pulp mass, about 20%.



18. Entanglement of spherical aggregates (arrow) with a strand-like aggregate (15X)

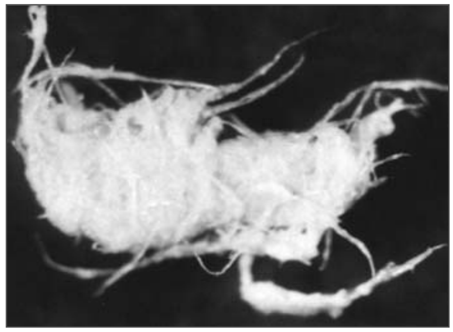


21. View of a spherical aggregate dispersed in water. The aggregate is made up with numerous tiny strand-like aggregates (4X).

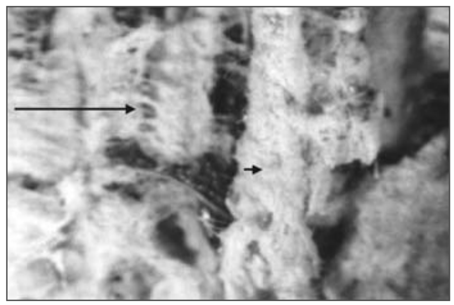
Regardless of their morphological nature, the aggregates had a relatively tightly held structure, implying that refining efficiency would be poor and fiber cutting extensive because the refining stresses concentration on the outer elements of the aggregates. That is, the inner elements are protected and receive less mechanical treatment. The fines are well kneaded onto fibers, as shown in Fig. 14, forming a protective layer over the fibers.

CONCLUDING REMARKS

The aforementioned conceptual chip refining mechanism in a pilot refiner confirms what was suggested to be a rolling mode (4). One of the difficulties encountered in this study is that no mobile aggregates (which were not anchored onto the refiner bars) are found in the refiner gap (0.5 mm) in the refining segment. This problem is believed to be attributed to the steam flush that could not be halted instantaneously when the motor was stalled. The presence of the so-called mobile aggregates between the refiner plates would certainly be of great



19. Entanglement of two spherical aggregates (15X)



22. One of the aggregates (short arrow) in the conical segment was being lifted out from the groove and rolled in the direction of rotation (long arrow) (4X)

importance for better understanding the theory of refining. Despite this, the proposed refining mechanism explains well the morphological and structural nature of the fiber aggregates at the refiner discharge. **TJ**

ACKNOWLEDGEMENTS

The author wants to thank the Natural Science and Engineering Research Council of Canada for its financial support. The technical assistance of Alain Marchand is greatly appreciated.

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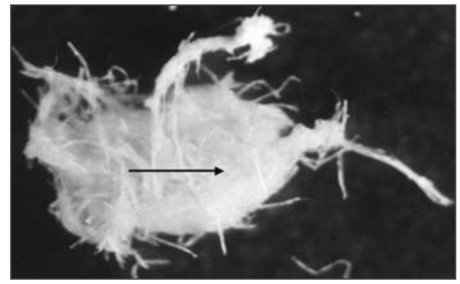
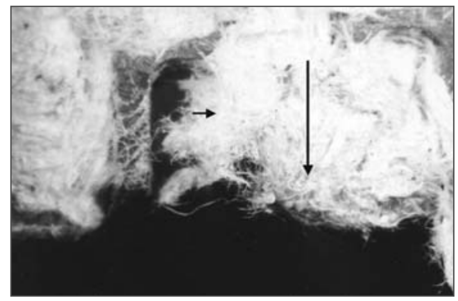


20. Most of the fibers in an oval aggregate are aligned in a common direction (arrow) (10X)



23. A partially lifted aggregate (short arrow) in a peripheral groove. Radial orientation (long arrow) of fibers is evident (4X).

Received: March 13, 2001
Accepted: July 23, 2001

This paper is also published on TAPPI's web site (www.tappi.org) and summarized in the January *Solutions! for People, Processes and Paper* magazine (Vol. 85 No. 1)

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