Effects of Recycling on Paper Structure

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SUMMARY

A study was made of the effects of recycling on the structure of paper using a scanning electron microscope (S. E. M.) and on the strength properties for correlation. The study showed a decrease of Burst, Tensile Breaking Length and Fold properties with recycling with a sulphite furnish. Bulk and Tearing strength increased with recycling. Observation with the S.E.M. revealed a decrease in the inter-fiber bonding intimacy of contact in the recycled compared to virgin sheets. Reduced intimacy could be attributed to reduced swelling suggesting that in order to achieve better strength properties on recycling may require improving the swelling ability of the fibers.

INTRODUCTION

A recycled fiber has been processed through at least one paper making cycle and so may be expected to differ from the virgin fiber in its properties. The changes which occur may be attributed to the effects of refining and subsequent drying. This may influence the intrinsic fiber strength, swelling of the fibers, the number of fiber to fiber bonds and their strength. Earlier investigatigation[1] has proved that the recycled fibers exhibit lower fiber strength and bonding potential than the same fiber in the virgin state. Those sheet properties which depend directly on fiber to fiber bonding and fiber strength decrease markedly with the number of recyclings. In contrast, sheet properties such as tearing strength, flexural stiffness, which in a sense are inversely related to bonding, increase with recycling.

The present investigation studies the change in the paper structure, fiber to fiber bonding, and the closeness of bonding by the direct observation of the fibers in a sheet of paper with a Scanning Electron Microscope. In order to correlate visual observations with paper properties, certain strength properties were also measured and are reported.

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EXPERIMENTAL PROGRAM

To study the effect of repeated recycling a series of repulping experiments were done using bleached softwood sulfite virgin pulp beaten to three different freeness levels in a laboratory Valley Beater. The freeness levels were 600 450, and 300 ml Canadian Standard Freeness (CSF). Stocks beaten to these levels were made into handsheets for testing the strength properties. The remaining stock in each case was made into sheets, pressed, dried, and saved for repulping. This completed one papermaking cycle. The dried sheets saved were repulped four separate times in the same way. Each time the pulp was beaten to the same initial freeness level of 600, 450, and 300 ml CSF, and handsheets withheld for testing. Recycling at 450 and 300 ml CSF levels was then continued to ten times without stopping in between for testing. After ten recyclings, handsheets were made for testing,—these handsheets provided the specimens for microscopic examination.

All the handsheets were tested for Bulk, Tearing strength, Tensile strength, Bursting strength, and Folding endurance. Papers of the virgin fiber and after recycling ten times were given a conductive coating of gold for the study of structure with a Scanning Electron Microscope (S.E.M.) The S.E.M. observations were photographs of the surface of the papers at areas chosen at random.

The negative of the S.E.M. photograph was projected by a photographic enlarger to estimate the bonded area at the interfiber crossings, Only the fibers in the surface plane were considered. The

bonded areas at fiber crossing were marked out on the projected photograph and measured. The effectiveness of contact in the crossings was readily apparent with the large depth of focus of the micrographs.

EFFECT OF RECYCLING ON SHEET PROPERTIES

The effects of recycling on sheet strength are tabulated in Table 1, 2 and 3 at freeness levels of 600, 450, and 300 ml CSF and are shown in Figures 1 to 6. The trend is similar to that of the earlier study of these properties with recycled Kraft pulp[1].

TABLE—1 EFFECT OF RECYCLING ON SHEET PROPERTIES, 600 ml CSF

(Bleached Sulfite Furnish)

Properties of Hand sheets	Number of Recycles				
	0	1	2	3	4
Basis Weight g/m^2	59.4	57.2	58.2	58.2	59.7
Bulk	1.61	1.64	1.68	1.72	2.87
Burst Factor	20.7	18.7	18.7	16 9	15.4
Tensile Breaking Length, m	3920	4270	3940	3670	3180
Tearing Strength Factor	88	97	102	110	119
M.I.T Fold Number	12	10	7	5	5

TABLE—2 EFFECT OF RECYCLING ON SHEET PROPERTIES, 450 ml CSF

(Bleached Sulfite Furnish)

Properties of Hand sheets	Number of Recycles				
	0	1	2	4	10
Basis Weight g/m^2	61.0	60.1	59.1	59.8	58.5
Bulk	1.47	1.56	1.63	1.68	1.64
Bursting Strength Factor	34.3	25.4	23.2	19.6	19.3
Tensile Breaking Length, m	6380	5040	4380	3980	4500
Tearing Strength Factor	78	87	91	86	67
M.I.T. Fold Number	32	12	10	6	6

TABLE—3 EFFECT OF RECYCLING ON SHEET PROPERTIES, 300 ml CSF

(Bleached Sulfite Furnish)

Properties of Hand sheets	Number of Recycles				
	0	1	2	4	10
Basis Weight, g/m^2	61.5	60.8	58.0	57.0	58.5
Bulk	1.36	1.55	1.58	1.60	1.60
Bursting Strength Factor	40.7	26.9	22.1	2.13	19.1
Tensile Breaking Length, m	6430	4680	4480	4380	4250
Tearing Strength Factor	66	71	70	71	73
MIF Fold	73	14	12	10	7

The effects of recycling on Bulk at three different freeness levels are shown in Figures 1, 3, and 5. Zero recycling represents the virgin fiber paper. It may be observed that the Bulk increases with the number of recycling at all freeness levels. Since the density of a sheet of paper at the same freeness level is proportional to intimacy of contact between fibers, the results indicates a decrease in intimacy of fiber contact with repeated repulping.

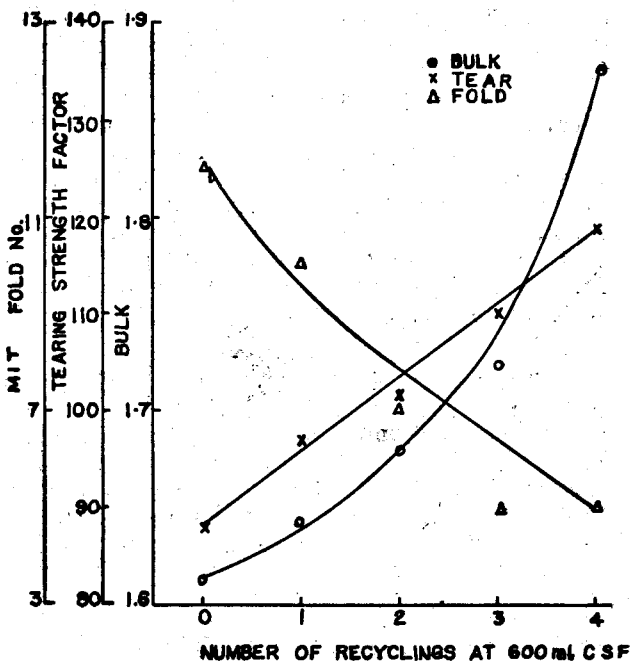

FIGURE 1

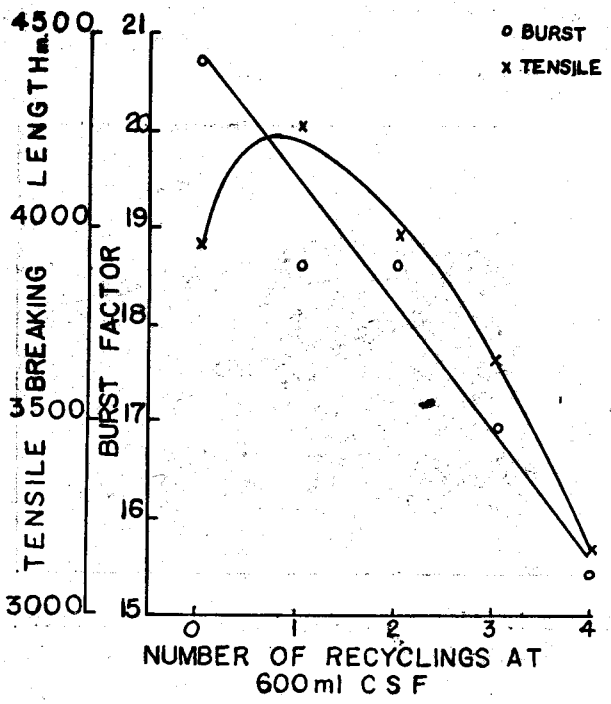

FIGURE 2

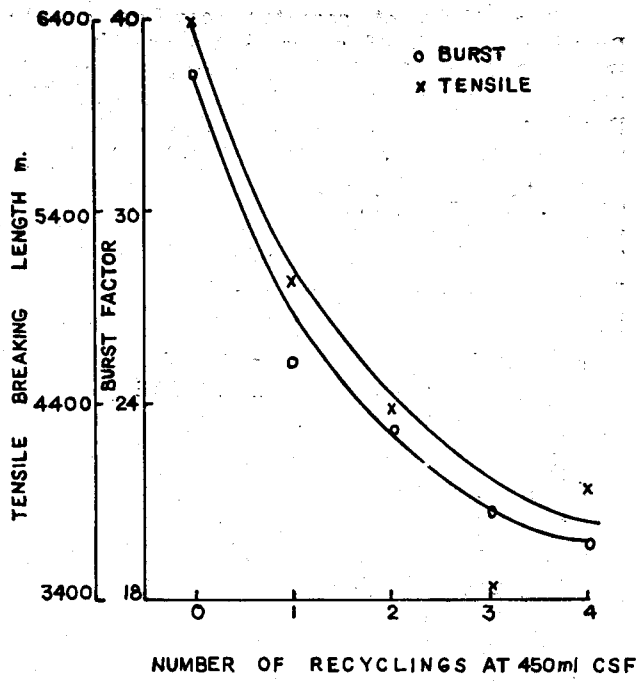

FIGURE 4

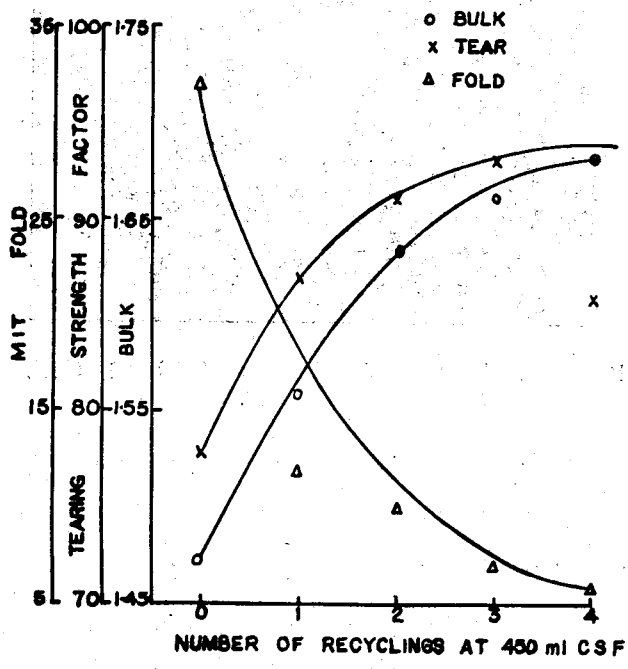

FIGURE 3

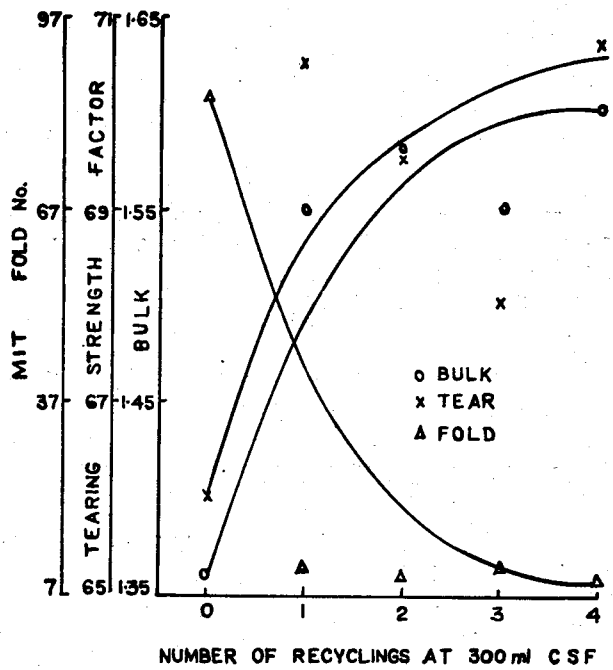

FIGURE 5

The effects of repeated recycling on the Bursting strength of paper sheets are shown in Figures 2, 4, and 6. Bursting strength decreased with repeated recycling at all freeness levels. The Bursting strength decreased markedly on the first stage of recycling, but afterwards the rate of decrease was less as seen from the slope of the curves. Figures 2, 4 and 6 also show the effect of recycling on Tensile breaking length of the paper. Tensile strength decreased with the number of recyling at all freeness levels, the rate of decrease also being greatest in the initial stage of recycling.

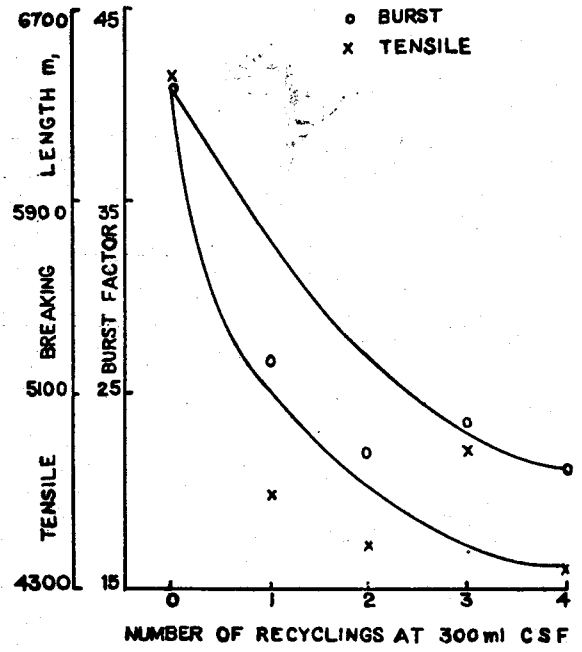

FIGURE 6

Tearing strength increased with the number of recycling as shown by Figures 1, 3 and 5 at different freeness levels. The total energy in tearing a sheet of paper is the sum total of the work required to rupture individual fibers and to pull the individual fibers from the fiber mesh. Figures 1, 3 and 5 include the effects of recycling on the Fold which also decreases with repeated recycling.

EFFECT OF RECYCLING ON SHEET STRUCTURE

The effect of beating on the sheet structure is seen in Photos 1, 2 and 3. These represent respectively unbeaten, beaten to 450, and 300 ml CSF virgin fibers. The photographs show an increase in the interfiber bonding which correlates with the increased strength properties on beating the paper. The number of fiber crossings, bonded area, and closeness of contact increases with beating. The photographs here and below are typical of all the many S.E.M. observations made.

Photo 1. Unbeaten Virgin pulp Magnification 200X.

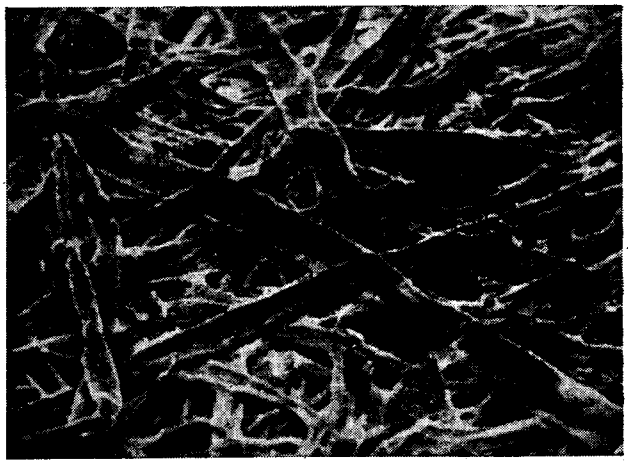

Photo 2: Beaten Virgin pulp (450 ml CSF) Magnification 200X.

The effect of the number of recyclings on the structure is seen at 200x magnification in the Photos 4a, 4b, 5a, and 5b. Photos 4a, and 4b show the sheet structure after ten recyclings at 450 ml CSF, and photos 5a, and 5b show the sheet structure after ten recyclings at 300 ml CSF. The bonded area at the fiber crossings calculated from the photographs showed a decrease in total bonded area with the recycling In case of recycling at 450 ml CSF, the bonded

Photo 3. Beaten Virgin pulp (300 ml CSF) Magnification 200X.

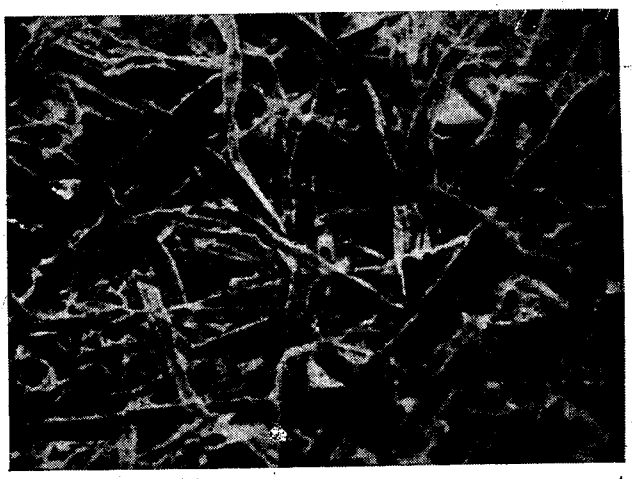

Photo 4a. Recycled Ten Times (450 ml CSF) Magnification 200X,

area after ten recyclings was 17% less than the virgin fiber sheet at the same freeness. For recycling at 300 ml CSF, the bonded area decreased 28% after ten recyclings compared to the virgin fiber at the same freeness. This is in accord with the fact, seen 450 and 300 ml. CSF, that the loss in strength due to repeated recycling at a lower freeness level is greater than at a higher freeness level. The bonded areas on fiber crossings were calculated without taking into account of the closeness of contact thus giving only the projected area in crossing. Strength properties such as Burst and Tensile of paper depends on the true area of interfiber bonding. Closeness of contact combined with the area are a measure of bonding strength. While the number of crossing of recycled fibers decreased compared to the case of virgin fibers, the true or effective area of contact between the fibers also reduced considerably, reducing thereby the total interfiber bonding strength. The relative closeness of contact of virgin fibers at 450 ml CSF is very clearly seen in the photographs at 1000x magnification. Photo 6, when compared to that of the recycled fibers at

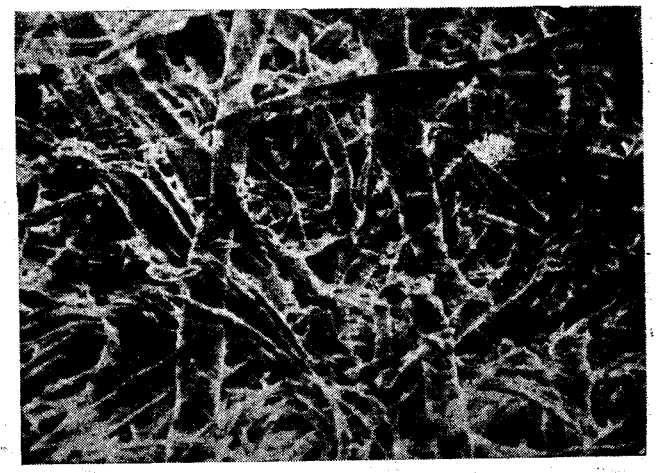

Photo 4b. Recycled Ten Times (450 ml CSF) Magnification 200X.

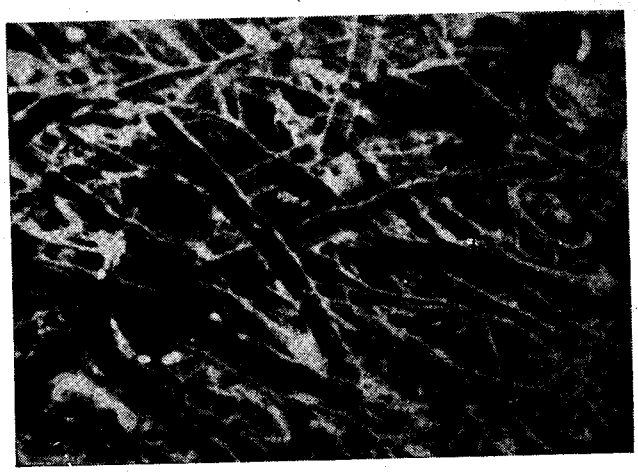

Photo 5a. Recycled Ten Times (300 ml CSF) Magnification 200X.

Photo 5b. Recycled Ten Times (300 ml CSF) Magnification 200X.

Photo 7a. Recycled Ten Times (450 ml CSF) Magnification 1000X.

Photo 6. Beated Virgin pulp (450 ml CSF) Magnification 1000X.

Photo 7b. Recycled Ten Times (450 ml CSF) Magnification 2000X.

same freeness and 1000x and 2000x magnification (photos 7a and 7b) show very clearly the difference in closeness of contact and interfiber bonding.

Though the increase in Bulk may be due to loss of fine fibers in repulping, it can also be attributed to less intimate contact between fibers in the thickness direction of the paper sheet. This is apparent in comparing photos of recycled to virgin fiber sheets.

The strength of paper can also change due to change in fiber dimensions, and the swelling of fibers during the wetting process for sheet formation. Investigation[1] has shown that the change in fiber length with repeated recycling is small. The cross-section of the recycled fibers seen from the S.E.M. photographs are reduced from that of the fibers.

The absorption of water by the fibers plasticizes the fibers increasing the true area of fiber contacts through increased flexibility. More intimate contact between fibers on drying provides closer bonding and better strength. This swelling property with water is gradually lost in repeated wetting and drying as evidenced by the photographs. In order to achieve better strength, therefore, attention should be paid to this aspect of the problem. The recovery potential of paper strength will be enhanced by increasing the swelling of the fibers by the use, for example, of swelling agents during repulping or of more energy in beating.

REFERENCES

1. Robert C. Makee, 1971 Effect of Repulping on Sheet Properties and Fiber Characteristics, Paper Trade Journal, p. 34, May 26, 1971.