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A NOTE ON THE PERMEABILITY METHOD FOR DETERMINING SURFACE DEVELOPMENT AND SWELLING DURING BEATING AND REFINING

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Introduction

The permeability method for the determination of specific surfacs (Carman[1]) of particles forming an unconsolidated homogeneous bed hae been applied by Robertson and Mason[6] to swollen pulp fibres. The permeability of the bed is measured at several bed concentrations and the data may be used to calculate not only a specific surface, but also a specific volume by suitable application of the Kozeny-Carman equation. The method has since been used by Corte,[3] Emerton,[4] Ingmanson,[5] Carroll and Mason[2] and others.

It has previously been reported[6] that the development of specific volume during beating as measured by this method ran parallel to the strength development as measured by breaking length or burst. On the basis of rather limited data, the suggestion was made that the two phenomena — swelling and strength development — might be closely related for a given pulp. At the same time, it was noted that a relationship appeared to exist between the specific surface and the drainage properties as measured by a freeness test. The same observations were subsequently confirmed by Corte[3] and in part by Carroll and Mason.[2]

The present note reports some subsequent work carried out at Svenska Träforskningsinstitutet, which generally confirms the previous picture, but suggests that the relationships are modified by the method of treatment.

Experimental

The method of making measurements is essentially the same as described previously,[6] although some refinements and improvements were made. The samples tested were commercial unbleached sulphite and kraft pulps. These were subjected to mechanical treatment in four different refiners — namely, Jordan, Voith refiner, Asplund refiner and Skardal refiner. Samples were withdrawn at various times in the refining process, formed into standard handsheets and tested for tensile and bursting strengths, tear, bulk and porosity. At the same time, portions of each sample were used to determine the specific volume α and the specific surface σ of the fibres by the permeability method.

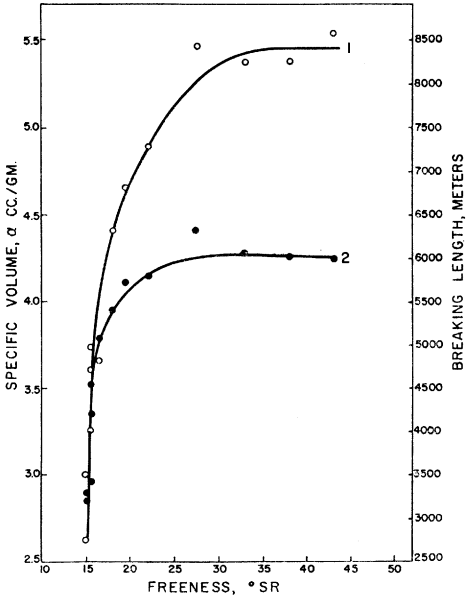

Fig. 1(*a*)—Breaking length (1) and specific volume (2) of a kraft pulp beaten in a Voith refiner plotted as a function of freeness

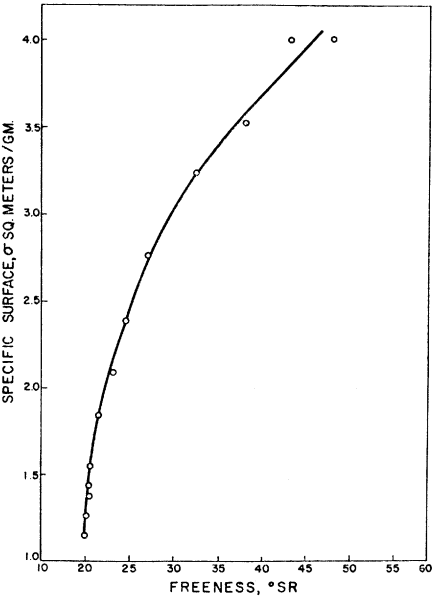

Fig. 1(*b*)—Specific surface of a kraft pulp beaten in a Voith refiner plotted as a function of freeness

Results

An approximately parallel development of strength and swelling was again apparent when both are plotted as a function of refining time, power consumption or freeness (Fig. 1*a*). A closer look at the results shows significant departures, however: for example, if breaking length is plotted as a function of the specific volume α (Fig. 2), approximately linear relations are

observed for the kraft pulps, but the sulphite curves show a decreasing slope with increasing values of α. Similar results are obtained on the basis of burst tests (Fig. 3). The curves also vary with the type of refining and this will be discussed below.

It may be pointed out that the starting material varied in specific volume α and breaking length, presumably as a result of variations in the soaking and disintegration of the lap pulp. The possibility cannot be disregarded that this initial condition influences the subsequent refining process to some extent.

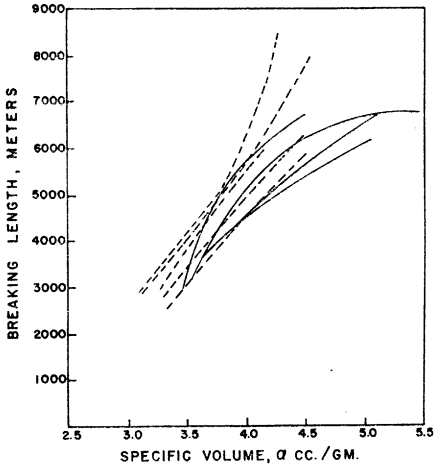

Fig. 2—Breaking length plotted as a function of specific volume for sulphite (solid lines) and kraft (broken lines) pulps for different conditions of beating

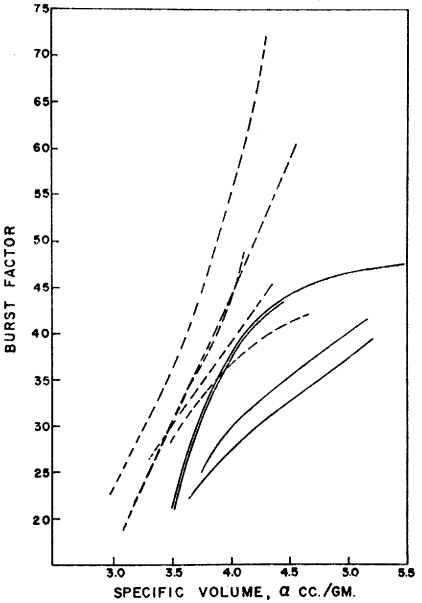

Fig. 3—Burst factor plotted as a function of specific volume for sulphite (solid lines) and kraft (broken lines) pulps for different conditions of beating

The parallel increase of swelling and strength might suggest a cause and effect relation; however, there are other factors to be considered. Swelling can be regarded as evidence of fibre damage and as such could, under certain circumstances, indicate weakening of fibres with a consequent loss of strength in the sheet. In addition, fibre shortening by a cutting action is not indicated directly by the measurement of either specific surface or swelling and thus represents an uncontrolled and unmeasured variable in these experiments.

If breaking length is now plotted against α at several values of σ (Fig. 4), the specific influence of swelling on strength may be examined. The data are few, but the following picture is suggested.

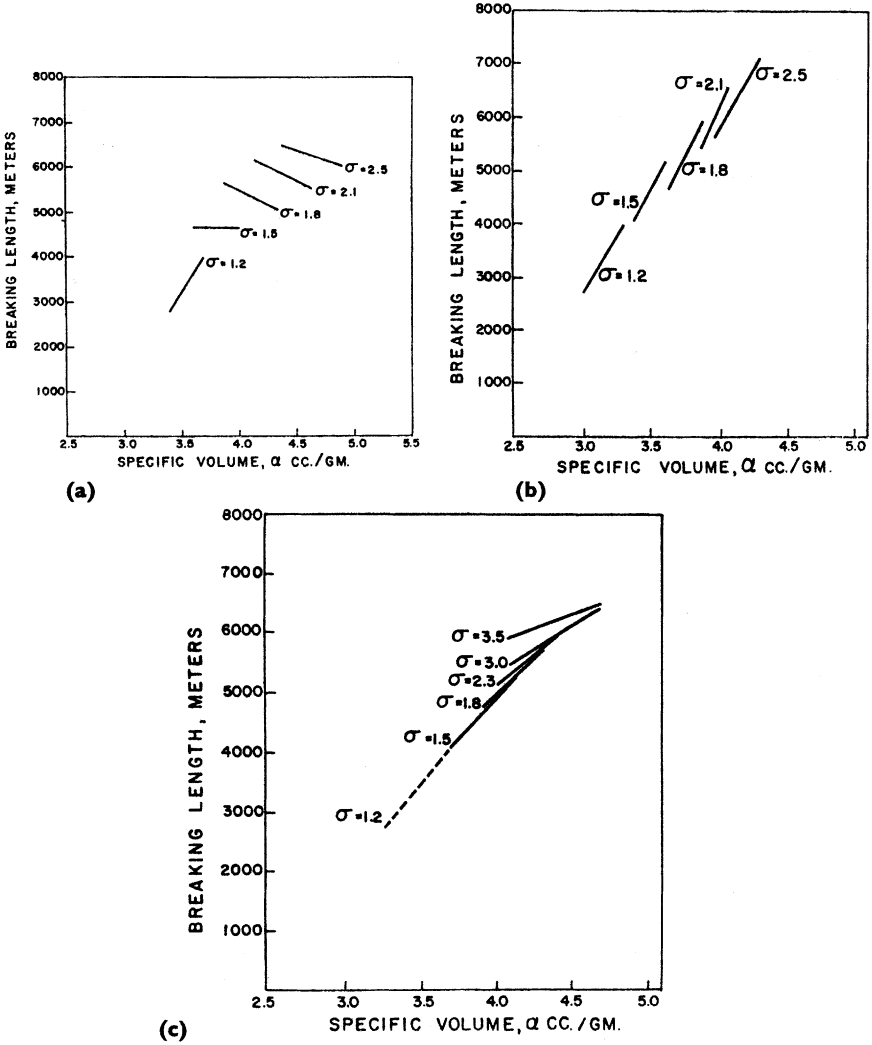

Fig. 4—Breaking length as a function of specific volume α at several values of the specific surface σ —

(*a*) sulphite pulp
(*b*) kraft pulp refined normally
(*c*) kraft pulp in a Skardal refiner

The sulphite pulp (Fig. 4*a*) initially ($\sigma = 1.2$ sq. m./g.) shows an increase in breaking length with increasing α; at $\sigma = 1.5$, breaking length is independent of α and at higher levels of surface development an increase in α at constant surface results in lower strength. When normally refined, the kraft pulp (Fig. 4*b*) shows increased strength with increased swelling at all levels of surface development. When given the drastic treatment of the Skardal refiner as used in these tests, however, the strength enhancement of an increased α becomes progressively less (Fig. 4*c*). This behaviour logically follows from considerations of the greater susceptibility of sulphite fibres to mechanical damage and the relative fibre-damaging properties of different

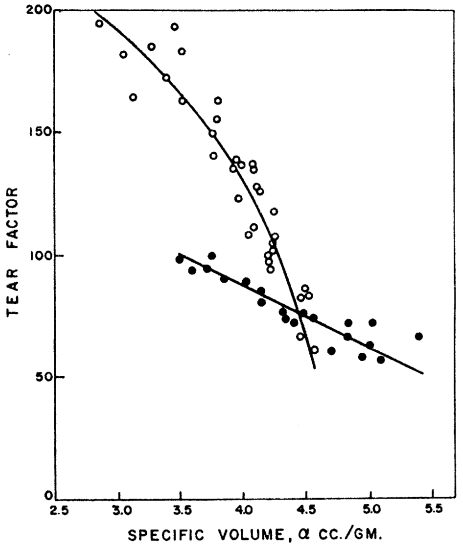

Fig. 5—Tear factor plotted as a function of specific volume for sulphite pulps (open circles) and kraft pulps (solid circles) variously beaten

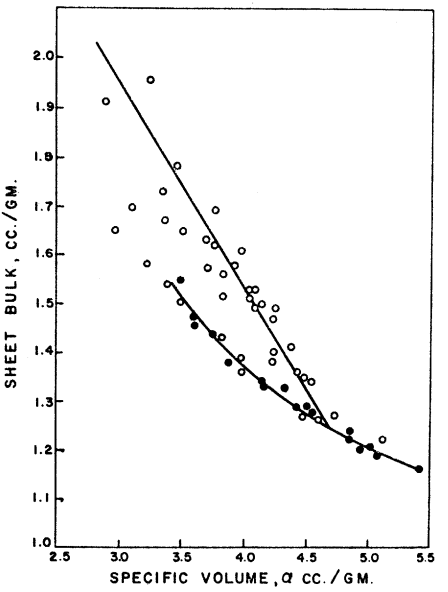

Fig. 6—Bulk plotted as a function of specific volume for sulphite pulps (open circles) and kraft pups (solid circles) variously beaten

refiners. The data from the present experiments appear to be inadequate to carry the analysis further, although the indicated dual aspects of swelling (that is, as an index of strength-producing processes and, under other conditions, as an index of fibre damage) would appear to require further attention.

The variation of other pulp and sheet properties with swelling and with surface-area development may also be determined. The variation in burst follows the tensile behaviour in a general way. At low degrees of beating, increased swelling at a constant surface enhances strength, whereas at higher degrees of beating increased swelling correlates with decrease in strength for the softer sulphite pulp and for the more drastic refining methods for both sulphate and sulphite pulps.

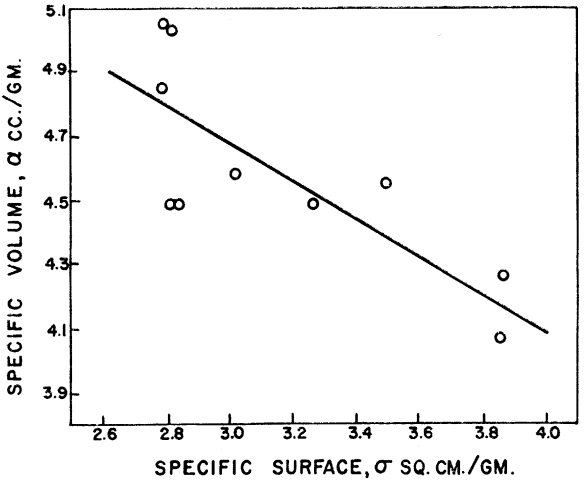

Fig. 7—Variation of specific volume α and specific surface σ at a constant freeness (40° S.R.)

The data obtained for tearing strength are advantageously plotted as functions of the swollen volume α (Fig. 5). The data tends to give two rather well-defined curves, one for sulphate pulps and the other for sulphite pulps, independent of the type of beating — that is, the scatter about the mean is unsystematic. The same trend appears for bulk measurements (Fig. 6), although one of the kraft Jordan runs showed a large unexplained deviation from the general behaviour. The remainder tend to give two curves — one each for sulphite and sulphate pulps. These relationships between tearing strength or bulk and specific volume α, although not precise, demonstrate a consistent behaviour that is not suggested when they are plotted against freeness or specific surface.

It has not been possible to demonstrate any definite correlation of stretch or porosity with freeness, surface area or swelling in such a way as to clarify the interpretation of the beating mechanisms.

Freeness is determined logically by both α and σ and should decrease with both — with the former because of increase in fibre flexibility, as it affects packing or compression and with the latter because of increased hydrodynamic resistance.

Though the data is inadequate to justify a quantitative relationship, it may be shown that at a given freeness there is a rough inverse relationship between α and σ (Fig. 7).

Summary and conclusions

Thirteen refiner runs have been carried out using standard sulphite and sulphate pulps under different conditions of refining. The specific surface and specific volumes have been determined for samples withdrawn at different refining times. Although broadly speaking, fibre swelling parallels strength development, the extent of swelling at a given specific surface can be correlated with loss of strength presumably as a result of fibre damage. This is apparent in later stages of beating with soft fibres or with drastic beating.

These data also indicate a relationship between tearing strength and the extent of swelling and possibly a similar relationship for bulk.

It is concluded that these first results indicate that the determination of surface development and swelling provides data of considerable value in the interpretation of beating and refining phenomena.

Acknowledgement

The author expresses his gratitude to Prof. B. Steenberg and Mr. O. Brauns of Svenska Träforskningsinstitutet for provision of experimental facilities and materials.

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DISCUSSION

MR. G. HUNGER: Dr. Gallay, you said you had displaced the water in the sheets by different solutions — how did you prepare the sheet?

DR. W. GALLAY: The sheets were prepared from the pulp stock in normal fashion up to the couching stage. They were then removed from the blotters and immersed in alcohol, drained, immersed in ether and dried in a vacuum desiccator over calcium chloride.

MR. HUNGER: A sheet formed in water will have thin layers of water at its contact regions, where one fibre touches the other. This water is kept there by hydrogen bond forces and I doubt whether it might be possible to extract this water by the different organic solvents applied. It may be very interesting to have a sheet prepared by putting a wet pulp into the different solvents — that is, to have the pulp standing for one night in the first solution, this being removed the next day, then suspending the pulp in the next solution and so on, lastly, forming a sheet from the fibre suspension in the last organic solvent. I wonder if you would still get the high strength that you found then. A pulp totally surrounded by the organic solvent would not have such a high strength, I think.

DR. GALLAY: We considered the method you have proposed, but felt that there were objections that would detract from the general principle. Notably, a radical change might be expected in the mode of deposition of the fibres from suspension in the organic liquid. We therefore consider it preferable to use water as the medium of deposition. It is considered from our data that little difference exists between beaten and unbeaten sheets in so far as thoroughness of water removal is concerned. It should be remembered that a very small residual amount of water is always associated with cellulose and removal of this residue is virtually impossible without radical decomposition of the cellulose.

MR. L. G. COTTRALL: I found Dr. Gallay's paper very stimulating, indeed. He has given us some new ideas, coming as he does from the plastics industry fairly recently. Whether they are right or wrong, these ideas make us think on new lines.

When he carried out his test of removing water by solvents, did Dr. Gallay try pulp that had been beaten in a ball mill a very short time? Some years ago, there was much controversy over how we got such a very large

increase in strength in a Lampén ball mill by beating for only 2 – 3 min. and various people had different ideas. I think it was the start of the idea of internal fibrillation as distinct from external fibrillation, when the surface of the fibre or the body of the fibre itself is damaged (*Proc. Tech. Sect. P.M.A.*, 1932, **13** (1), 15), although I believe the term was originally due to W. B. Campbell. Really, I do not know whether we have at the present moment a satisfactory explanation of that very great increase in both tensile and bursting strengths with a very slight reduction in tearing strength. In the case of sulphate pulps, the tearing strength is in fact increased over this small range of beating.

Has Dr. Gallay tried testing sheets in that way and has he found that there is still that same great increase in strength when these sheets have been treated with alcohol in the ordinary way or that there is a great reduction in strength through that process?

DR. GALLAY: The direct answer to Mr. Cottrall's question is that we have been thus far using only the Valley beater in this work for strength development.

Certainly we must examine closely any unusual results obtained with specialised beating methods, since these must add to our knowledge of the potential resident in the fibres, if they are treated in better fashion. The sort of result Mr. Cottrall mentioned can be obtained by beating in a rubber-lined ball mill with rubber-covered balls. Clean-looking fibres with high bursting and tensile strengths and well-preserved tearing strength can be obtained.

It would be most interesting to examine such pulps from the point of view of separation of fibre friction and bonding.

MR. G. VAN NEDERVEEN: I think the question put forward by Dr. Gallay is one we also know in Holland. We met the problem how to beat fibres without decreasing the tearing strength too much. For beating experiments in the laboratory, we use the Lampén mill and an apparatus that is nothing but a kitchen mixer (we call it a Vimix), turning at 12 000 r.p.m. The tearing strength of laboratory sheets made from Lampén mill beatings is definitely lower than that from Vimix beatings. The breaking length is somewhat higher with the Lampén mill than with the Vimix for high freeness; but, at the end, the Vimix breaking lengths come up to the same level as those with the Lampén mill. I mean, the Vimix does really beat the fibres and is not only a disintegrator.

When you examine under the microscope fibres beaten in the Vimix, you will see that this mixer does not cut the fibres very much: the fibres are

not shortened by this beater. With cuprammonium solution one finds balloons in a few places on the fibre wall. This means that there is indeed some kind of external fibrillation proceeding in the Vimix.

With this apparatus, therefore, we succeeded in getting high tearing strength, the fibres being beaten but little damaged.

DR. GALLAY: I am very grateful for this additional contribution; it is typical of what I have noted and what may be expected if the integrity of the fibre is preserved.

As you will have gathered from what I said this morning, I dislike gross fibrillation as a component of the beating process. I wish to make my position on this matter quite clear. If the objective is to manufacture greaseproof or glassine or, in general, if permeability to gases and liquids is an objective, then undoubtedly extensive fibrillation is difficult to avoid or may indeed be necessary. If we restrict our objective to strength factors and associated properties, however, then I would wish to reduce this gross fibrillation to a minimum.

MR. P. E. WRIST: There is one particular aspect of fibre preparation that has not been mentioned so far and should not be forgotten. In practice, we are not dealing with fibres of uniform dimensions. When we form a sheet, we assemble fibres of differing shapes and sizes. The fibre length distribution influences the way in which fibres will pack together. We may get greater strength in a sheet, not by developing bonds, not by increasing the flexibility, but by adjusting the fibre length distribution in such a way that the fibres can form together better. I think this is what the papermaker is primarily trying to do with his machine Jordan. Unfortunately, he can only cut the fibre this way and that not selectively, thus he obtains the improved formation and the resulting increases of bursting and tensile strengths at the sacrifice of average fibre length and corresponding tearing strength.

Mr. Chairman, on Wednesday, you said that ten years ago there was much more beating done than today. I think this is probably due to the increasing blending of pulps, whereby some of the results of beating can be achieved without its use. I believe we should not overlook in our discussions the importance of optimum fibre distribution for optimum fibre packing.

MR. G. F. GLOVER: In the first few minutes of beating, even with quite a low roll pressure, there is a very rapid increase in strength properties. I think that agrees with the idea of internal fibrillation, but the main point is that the fibre is made more flexible in those first few minutes (even seconds) and the

surface tension forces cause the fibres to bed down much more securely in the sheet, giving far more possibility of bonding. There is an increase in sheet density almost immediately in the first few minutes of beating.

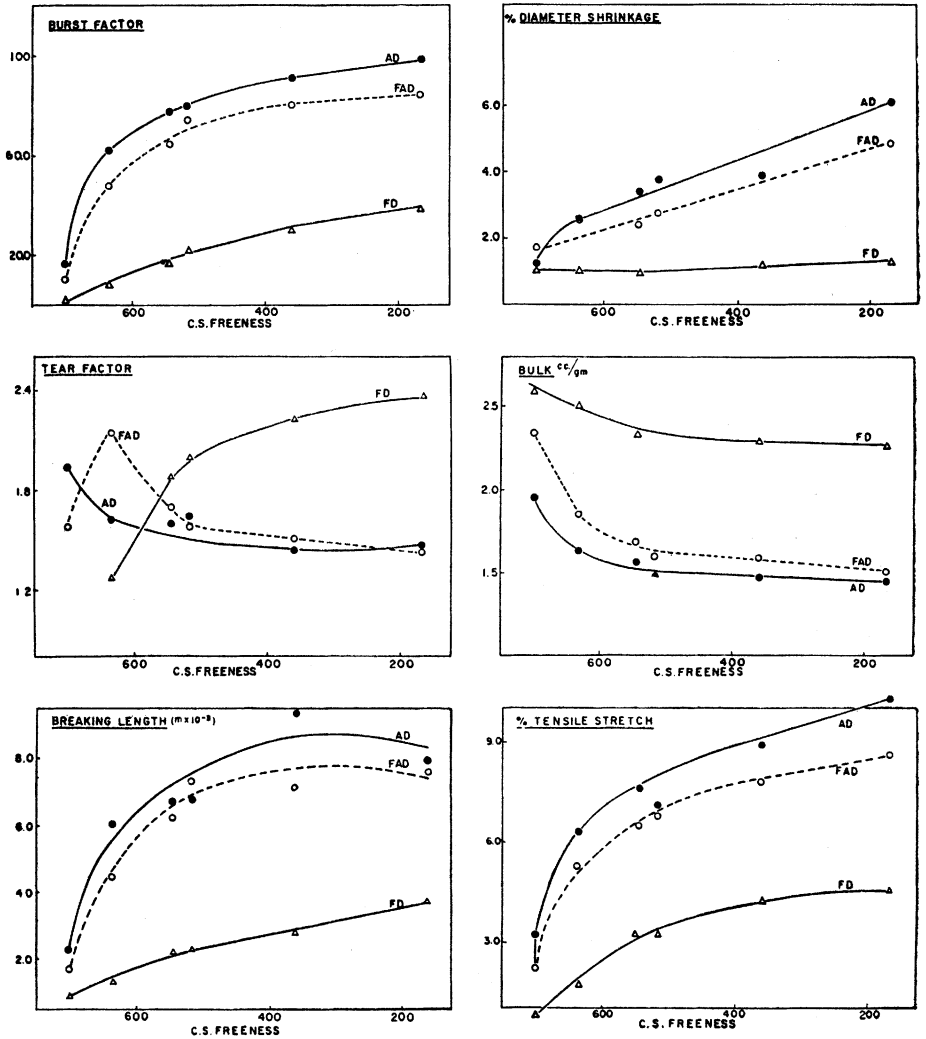

Fig. T — Variation of physical properties of freeze-dried (FD) and air-dried (AD) standard handsheets on beating — FAD designates a control series in which the wet pulp was frozen and then allowed to thaw before preparing air-dried handsheets

(From Marchessault, Lodge and Mason, *Svensk Papperstidn.*, 1956, **59**, 859)

DR. S. G. MASON: In his spoken remarks, Dr. Gallay speculated on the possibility of beating without sacrificing the tearing strength. It may be of interest to know that we were able to accomplish this by beating in the normal way in the Valley laboratory beater, forming standard handsheets and then freezing the wet sheets and evacuating them so as to remove the water by sublimation. This effectively eliminates the surface tension forces normally present when drying from liquid water. The results are illustrated in Fig. T.

It should be emphasised that by freeze-drying we have not completely eliminated interfibre bonding — that is, the freeze-dried sheets are not held together by frictional forces and fibre entanglement alone. In these experiments, sublimation was carried out at about – 10°C; however, once we get below a certain moisture content, which depends upon the water sorption isotherm, the 'freezing point' of the water associated with the cellulose is less than – 10°C. Thereafter, we may consider that the water is removed from a solution of 'liquid water' in cellulose; thus, the last stages of freeze-drying are basically no different from those in evaporation drying.

DR. GALLAY: I fully agree with the statement made by Mr. Wrist on fibre distribution. It would certainly appear logical that some filling of voids with fibres of suitable length should enhance entanglement.

I am reminded of the excellent work carried out by Prof. Brecht on the wet strength of mechanical pulp, from which he concluded that the highest possible wet density was required for maximum tensile strength.

I agree also with the remark by Mr. Glover and I interpret that by concluding that there simply has not been time for appreciable damage to occur during the first portion of the beating curve.

With regard to Dr. Mason's remarks, we have not made a study of the freeze-drying method. I am rather surprised at the relatively small loss in tensile strength shown, but hesitate to comment further in a field that is unfamiliar to me.

MR. G. F. UNDERHAY: I have two points. One is that I thought Dr. Gallay's unbeaten strength figures with which he compared the strengths of his pulp after the alcohol washing were very low indeed. It seemed to me that for that reason the ratio was rather higher than it should have been.

The other point was that I heartily endorse and agree with what Dr. Gallay said about the incidental properties that arise when you are beating pulps. Once again, does it not underline the fact that wetness development is not only an incidental property that you may not want, but that, if you do want it, it is very badly measured by the Schopper-Riegler instrument?

DR. GALLAY: The last part of Mr. Underhay's remarks I agree with heartily, but his first point requires clarification. The pulp used was a normal sulphite pulp of average strength. Due regard must be paid to the fact that these sheets were air-dried and not pressed after couching. The published paper will deal with this further.

THE CHAIRMAN: I think we must end the discussion on Dr. Gallay's paper; time is up. Mr. Cottrall, you wish to say something?

MR. COTTRALL: Dr. Gallay is assuming that filling in the spaces in the paper with little bits and pieces increases the strength of the paper. We heard, the other day, that fines in paper add nothing to the strength of the paper.

THE CHAIRMAN: Summing up this discussion, it shows that there is much more to it than is apparent. Personally, I think the important points that have been brought out by Dr. Gallay's paper can be stated in the following way.

In the last few years, we have had a deluge of hydrogen bonds over the paper industry; everything in paper is suddenly hydrogen bonds. This is probably due to the fact that so few people in the paper industry and in research really know what a hydrogen bridge is. There are many types of hydrogen bonds. We certainly know that the hydrogen bridge can be quantitatively calculated only in very few extremely simple circumstances. It is a nice concept, however, because it is easy to understand and to apply qualitatively. Thus, everybody jumps to it.

MR. HUNGER: I am afraid we have now built up a Tower of Babel in the nomenclature of the cell walls. According to the classic terminology of Kerr and Bailey, we have a primary wall and secondary walls nos. 1, 2 and 3. Bucher has reintroduced the term tertiary wall and Meier has introduced that of a transitional lamella. Today, it seems that the primary wall Prof. Giertz spoke of corresponds to the outer secondary wall referred to by Mr. Emerton. I strongly support Mr. Emerton's proposal published some time ago that, until there is definite proof to the contrary, we should use the terms of Kerr and Bailey only.

MR. VAN NEDERVEEN: I want to thank Prof. Giertz for this lecture, because I found most of our own experiences embodied in the ideas he put forward.

My interest, too, was aroused by J. d'A. Clark's article in the book by Ott, *Cellulose and its derivatives.*

At the Fibre Research Institute in Delft, our observations indicate that the values obtained with the Schopper-Riegler instrument are composite values, in which the influence of more than one property of the pulp suspension is hidden.

Swelling, fibrillation and shortening of the fibres are three phenomena that contribute to the beating degree found with this apparatus. We therefore use the Jayme swelling measurement and that of fibre length distribution with the HS apparatus. An impression of the fibrillation is obtained by determination of the specific surface of the fibres with the Robertson and Mason apparatus. In this way, the three factors that each contribute in their own way to the ultimate value of the beating degree are measured separately.

Our investigations on beating have been carried out with various laboratory instruments — a Lampén mill, a Jokro mill, a Valley beater and a modified Turmix (kitchen mixer). Applying these methods and also checking the effects of beating with the phase contrast microscope, we found the largest divergency in beating effect between the Lampén mill and the Turmix. We think it useful always to use these two instruments in studying the beating behaviour of an unknown pulp, just because of the very different effects they have.

For mill control, the determination of swelling, the fractionation with a classifier and the measurement of specific surface would take too much time. Now Ivanov (Leningrad) and Imset (Oslo) have developed rather simple instruments for getting a quick impression of the fibre shortening and the swelling separately but in one operation. We think both of these instruments would be very valuable tools in mill practice.

Has Prof. Giertz had any experience with these two instruments?

PROF. H. W. GIERTZ: I can very rapidly answer the question about the different apparatus. I do not know about the Ivanov apparatus, but I am fairly familiar with the Imset one, which measures the shortening of the fibres and at the same time the swelling degree of the long fibres. I say swelling, but, as the method is based on centrifugal forces, it is more or less the same kind of retained water that is measured with Jayme's method. As I know that only a small part of such retained water has to do with swelling and that the main part more accurately ought to be called entrapped water (held by the fibre in the lumen and other pockets), I do not think it is a suitable instrument for laboratory work. Whether it is a good apparatus in the papermill, I do not know.

MR. COTTRALL: I would really like to know something about this swelling. In his paper, Prof. Giertz makes a reference to me in relation to the considerable importance I attach to swelling. I certainly do, so far as the unbeaten part is concerned, but I am not quite clear how to get information on the amount of swelling when the fibre is beaten. Let us take a dry fibre: put into water, it swells considerably. I think you will all agree with that. Then you beat this fibre, either by internal fibrillation by breaking the bonds between some of the cellulose fibrils or by external fibrillation by taking pieces off the surface or by splitting the fibre or by all three methods. My point is, if you add the volumes of all these pieces together, is the sum of these very much greater than the volume of the soaked, unbeaten fibre — or are you, when you are considering swelling, taking the external boundary of the fibre, including all the voids derived from the internal and external fibrillation of the fibre? Assuming the length of the fibre is unaltered, is the volume of the fibre (obtained by multiplying the length by the average cross-section comprised of the sum of the body of the fibre plus the sum of the areas of all the external fibrils) any different or very much greater than the volume of the soaked, unbeaten fibre (*cf.* Kress, O. and Bialkowsky, H., *Paper Trade J.*, 1931, **93** (20), 42)? It is indicated in Prof. Giertz' paper and in other papers that the volume is very much greater and I should like the point to be clarified.

Another point in connection with the effect of hemicelluloses referred to in Prof. Giertz' paper, is what would happen in the case of a fibre that contains no hemicellulose, such as a rag fibre?

I am not suggesting that external fibrillation is an advantage for most papers, but most swelling measurements have been made when the fibre is appreciably beaten and there is considerable external fibrillation. It is when there is appreciable external fibrillation that we get the high figures recorded for so-called swelling. I do not regard these as representing measurements of true swelling.

PROF. GIERTZ: But you get this fibrillation at such a very late stage of beating that it cannot play any role for ordinary papers. If you make a bond paper or a greaseproof paper, however, it may play quite an important part. I have explained this in my paper.

MR. H. W. EMERTON: In his paper, Giertz says, "the fibre splits in the longitudinal direction and forms fibrils." I should like to underline a fact that I have repeatedly emphasised, that, to a much greater extent than is realised, external fibrillation is not in the form of longitudinal strings, but is in the form of sheets or membranes.

The bulk of the cellulose in mature fibres is in the middle secondary wall in the form of co-axial layers of microfibrils, the tangential surfaces of which are encrusted with hemicelluloses. Such lignin as is present in the cell wall occurs between these co-axial polysaccharide layers. Thus, the removal of lignin by cooking predisposes the structure, when mechanically treated, to disintegrate into thin membranes. It is, to a large extent, the effect of surface tension drawing these together, also folds and turned up edges, that lead to the impression that long, thin fibrils are seen.

THE CHAIRMAN: On Mr. Emerton's paper, I must say that in transmission electron micrograph experiments carried out in Stockholm by Dr. S. Asunmaa on bonding in paper — studied by the serial cutting of pieces of paper to about 100 Å thickness — you can see that quite large bonding areas occur. You can also, because of the osmium penetration, easily identify the S1 layer. Consequently, it is frequently possible to identify the part of the cell wall in such fibre-to-fibre contact areas. We only consider electron-optical contact areas. Whether such contacts mean bonding or not is uncertain, but the fibres frequently appear welded together even in high resolution micrographs. The probability that we are here dealing with bonds is much higher of course than in the experiments of Nordman discussed yesterday. Such welds are found between all the layers. We have observed such areas between S1 and S1 layers; we have them between S1 and S2 layers; we have them between S2 and S2 layers. We also frequently observe a collapsed lumen when it is impossible, even at high resolution, to observe anything but an electron-optical contact.

Consequently, I think it is an oversimplification to say that we want to take away S1 in beating to have the benefit of S2 bonding. I think there is no evidence that bonding is better between S2 and S2 layers. I think that all types of bonding occur between all the variables and, after all, if we still believe in the hydrogen bond, all surfaces are profuse with hydrogen bonds, so there is no reason from that point of view to assume that bonding could not occur between all layers.

Furthermore, I think Mr. Emerton does not intend to say what could be read into his paper, that you can carry out beating so nicely that you remove just the S1 layer. As a matter of fact, in micrographs of all beating products, sheaves or flakes, loose fibrils or whatever they are named are formed by splitting fibres more or less at random. Only seldom does the split occur at or near the S1/S2 boundary.

That brings me to the second point about the fibrils. All fibrils discussed in the papers are the fibrillar portions of a fibre. This is what you first see in

the microscope, because, when you focus, you will focus on the fibre, but not on the slide below it. On that slide, you would see loose fibrils, also separate entities that I will call chips (or sheaves or something like that), which are free. Many fibre microscopists never see them, especially when using Herzberg staining solution, because this agent swells these loose particles so that they are practically dissolved.

By pouring pulp into a shallow trough with a bottom made of teflon foil and allowing the water to evaporate at 60°c, examination under the light microscope shows a great quantity of fine material, woolly and hairy — just like the hairs in a horse's tail — all over the picture. This material was lost in the whitewater in the process of making a sheet of paper from the pulp.

I think that Mr. Emerton may be right. He thinks that the material coming off the fibre in the beating process is flakes — the material looks hairy to me. It may, of course, be possible that the flakes have rolled up into bundles in drying, owing to surface tension forces. Cross-sectioning of such material has, however, not forced such a concept on us.

If we take the whitewater from the sheet made on the wire and evaporate it on the teflon foil, we see it is a mass of small particles intermixed with a few long fibres that have passed through the mesh.

The point I have tried to make is that, in beating, even at its early stages, a great mass of fibrils is torn off the fibre. Very probably there are more loose fibrils than those still adhering to the fibres. Van den Akker's paper on the forces required for tearing loose a fibril makes it understandable that the probability may be higher for the particle to be completely torn off than left partially intact, once the tearing process has begun.

If we discuss fibrillation in beating and paper properties, we cannot ignore this material.

MR. EMERTON: I think there is no real disagreement between us — just a question of emphasis — on this matter of longitudinal fibrillation. We must not accept too readily the idea of fibrillation being in the form of long, thin fibrils.

I did not mean to imply that it is desirable during beating to remove S1 in order to get bonding between S2 layers in adjacent fibres: that may or may not be so. My argument was that it may be desirable — I do not state dogmatically that it is — to remove S1 simply to enable the fibre to imbibe plenty of water and become more plastic.

THE CHAIRMAN: I think I was not the only one who thought that you stressed the point too much, so I just wanted to give you a chance to put it right.

DR. H. MEIER: I do not quite agree with Mr. Hunger that the primary wall of Prof. Giertz has become synonymous with the secondary wall of Mr. Emerton. As far as I understood it, Prof. Giertz really meant that only the primary wall is removed during beating, whereas Mr. Emerton meant that S1 is removed, too.

Probably, the only technique with which to resolve this question is that of metal shadowing used by Mr. Emerton. It is possible by this means to distinguish clearly between the crossed fibrillar structure of the primary wall and the parallel structure of S1.

DR. B. G. RÅNBY: Firstly, I should like to say that the S1 layer in the cotton fibre is called the *winding layer* and that term is used rather extensively in the U.S.A.

Secondly, I should like to fulfil an intention of two days ago and speak this afternoon about recent work on hydrogen bonds, especially in cellulose. What we know now about them gives some explanation how it is possible at all to beat a pulp containing no hemicellulose and to make such strong paper from it. I should also like to show how amorphous cellulose can react with water in the same way as hemicellulose.