Preferred citation: W. Gallay. Summary and appraisal. In **Consolidation of the Paper Web**, *Trans. of the IIIrd Fund. Res. Symp. Cambridge, 1965*, (F. Bolam, ed.), pp 1013–1025, FRC, Manchester, 2018. DOI: 10.15376/frc.1965.2.1013.

SUMMARY AND APPRAISAL

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I DEEM it a great honour to have been assigned the important task of summarising and appraising the contributions made to this symposium. My particular task under the most favourable of circumstances is an onerous one, but I was placed under the considerable handicap of having received the preprints later than any of you. Owing to a postal strike in Montreal, there was a delay of three weeks in my receiving the preprints, which constituted a minor disaster in my schedule of time available. I have however done the best I could under the circumstances in studying the enormous amount of material presented.

I am very pleased that I have at least one minor advantage to offset this handicap, namely, that there will be no public discussion of my remarks this afternoon. If therefore I make some rather stupid error (which is quite likely), I can always revise this on further thought in making my written contribution and can claim like the politicians that I was misquoted and misunderstood in my verbal presentation.

In preparation for my own part in this symposium, I examined the meaning of the word *appraisal.* My dictionary puts the following meaning to the word—to appraise means to set a value upon, by authority of law or agreement of interested parties. To this, I can comment that I am quite sure that my appraisal will not have the authority of law and I am equally sure that it will not have the agreement of interested parties.

Before proceeding with my summary and appraisal, I have only two minor notes of mild criticism, which are offered in a constructive vein and which I hope will be received as such. A review of a topic is a very valuable thing and a well-done, well-organised and annotated review is something we all like to read and something that we find very useful. I am not at all sure, however, that an uncritical review serves any useful purpose as part of a symposium such as this, if only for the reason that it presents no material that can be commented upon, criticised or analysed for further use. I would humbly suggest to the symposium committee therefore that, in my view, in the future by all means include reviews of topics, but that such reviews should be analytical and critical in nature, with certain deductions made by the reviewer, which he is then prepared to defend in discussion. This kind of review in my opinion serves a very useful purpose in obtaining the greatest value from researches already reported and in preparing the ground for new viewpoints and new avenues of attack on a problem.

My second minor point of criticism is directed at many of the authors and indirectly also at the chairmen. It has to do with the material of the presentation. Preprints lose much of their value if time is taken by the authors to present such material as apparatus, experimental procedure and the like. The material presented from the actual written paper should be limited to a brief account of why the work was done and a summary of the results obtained and the conclusions drawn. In addition to more time for general discussion, this would allow for some speculation on the part of the speakers on matters that they would not care to have go on the record, but would stimulate discussion. They could be in favour of sin, they could be against motherhood, they could even go to the terrible limit of saying that there is no hydrogen bonding between cellulose and water!

Several authors have given essentially similar definitions of the term *consolidation of the web* and, in general, we take it as the sum total of drainage, pressing and drying on the web previously formed. It is obvious, however, that there can be no line of demarcation between formation of the web and the early portion of consolidation and very properly in my opinion, therefore, authors have discussed formation to some extent, even fibre networks at low concentrations. At the other end of the interwoven series of events, consolidation must be evaluated in terms of sheet properties and structure and this has also been properly included in the material of this symposium. Since cellulose/water relationships constitute the root basis for all of this, we have been properly concerned with these matters, too. In the manufacture of paper, we know that any result to be obtained by any procedure at any stage will be strongly influenced by everything that has preceded it in the history of the fibre constituents and their combinations. In other words, while we can direct our attention mainly to the events of consolidation, we must in so doing discuss to some extent virtually everything in papermaking, including stock preparation. This has been done during this symposium and, in my opinion, properly so.

I propose this afternoon to regroup as best I can the highlights of the contributions to the symposium in the form of a running commentary in sequence roughly in the order of papermaking operations. This is not an easy matter, since there is of course a great deal of overlapping and piecing together. In so doing, I make no pretence of dealing with all the important facts brought out by the various authors. These you will no doubt have noted for your own purposes and for your thinking and consideration. A summary and appraisal must of necessity be in the main fairly general in nature and reasonably brief, considering the volume of material to be taken into account.

Networks and drainage

STEENBERG, THALÉN & WAHREN have presented us with a very interesting concept of the relationship between structure and properties in fibrous networks, based on a model that takes into account fibre length as well as thickness. These authors have calculated that the minimum concentration at which the network can exist, for pulp fibres with a high axis ratio, is of the same order as that obtaining in the head box or just after the slice on the papermachine. The concept of the structure of a fibre network in suspension is one of fibres locked into the structure by internal strains brought about by previous agitation. The series of researches by Steenberg and his colleagues, which have been presented to use in summary form, will be of great assistance to us in our considerations of the flow and other properties of fibre suspensions. I shall return in a moment to a consideration of the application to the formation and drainage of the web on the wire.

Radvan, Dodson & Skold, through a novel means of examination of the positioning of the fibres in the formed web, have come to the conclusion that the fibres are strongly layered and that the degree of felting is probably of a minor order. In a further examination of the mode of deposition of the fibres on the wire, they have presented strong evidence that the process of water removal, at least in the earlier part of drainage, is one of filtration rather than of the thickening of a network. They have then pointed out that a process of filtration must produce a layered structure. The concept of a layered structure is of course in accordance with the great majority of conclusions reached from diverse investigations previously reported.

It is of interest now, before proceeding further with other papers on formation and drainage, to examine whether there is a conflict between the concepts expressed in these two papers by Steenberg and by Radvan. Steenberg has stated that consolidation of the paper web commences shortly after the slice, on the basis apparently that a structure already exists at that point and that consolidation proceeds through drainage and subsequent processes. This would involve a thickening process and, for the earlier portion of drainage on the wire, this would be at variance with the conclusions drawn by Radvan. It would appear to me, at least from a qualitative standpoint, that the relationship between these two mechanisms is governed by the forces obtaining in the system. Under the influence of the shear gradients that obtain after the slice, the relatively low strength of the network is probably insufficient to withstand disruption and individual fibres or very small groups of fibres can be deposited as a mat on the wire. As the process of drainage proceeds, the network concentration must increase with consequent increase in shear modulus and resistance to disruption. Eventually, further drainage will proceed through thickening of a relatively strong concentrated network. It would appear on this basis that these two conclusions from Steenberg and from Radvan are additive in presenting us with a picture of a gradual change from layering to thickening. Since thickening must involve a somewhat greater degree of felting, then we should have in the final sheet a gradation of certain physical properties such as stiffness from wire side to top side. It would be of interest to obtain further quantitative evidence of such a gradation in the properties of paper in the thickness direction, particularly in sheets that are reasonably free from the disturbing influence of obvious flocculation.

Continuing with this area of water removal, Higgins & de Yong have studied the compaction of fibrous mats under the influence of relatively small externally applied pressures. Their work is therefore related to drainage on the wire rather than to later wet pressing. From their studies, they concluded that the rheological properties of the fibre mat during drainage depend to a large extent on the flexibility and lateral conformability of the fibres involved. Stiffer fibres will assume a different position relative to one another during flow under the applied stress. More flexible fibres have greater resistance to this displacement and, with such fibres, the movement is one of elastic deformation of the flexible fibres and of the network. This relationship between fibre properties and rheological properties of the network in compression and recovery under an applied stress aids greatly in our concept of what happens during drainage and, as the authors point out, it would be valuable to extend this area to a broader range of applied stress and network concentrations.

A mathematical model of high-speed filtration that shows satisfactory agreement with direct measurements has been presented by Meadley. Here again, it is interesting to note the major effect of the degree of flexibility of the fibres in the mat. This flexibility is a governing factor in the rate at which the mat builds up on filtration, in the sensitivity of filtration rate to applied pressure and in the density profile with distance from the wire.

In one portion of his contribution on formation and forming variables, Norman has presented evidence of a practical solution to the problem of using a more dilute stock in the head box in order to attain greater uniformity of formation, when the wire length is insufficient for water removal by standard means. He has proposed the principle of the use of a very low vacuum distributed over a large area of the wire in order to increase the drainage rate and thus have the benefits in physical properties and uniformity of formation resulting from the avoidance of gross flocculation. Much the same effect has recently been produced elsewhere through the use of vacuum boxes distributed in various arrangements early along the wire and operating under low head. The results obtained by Norman on a full-scale papermachine are of intense interest from the practical point of view, as well as giving us more information about the relationship between drainage time and applied pressure in the low pressure range.

The contributions we have had on the subjects of web formation and drainage have advanced our knowledge considerably. To my mind, they have emphasised one point in particular—and this is not surprising, since it might have been predicted—namely, the extraordinary importance that must be attached to the flexibility of the fibre components of the web as they arrive at the beginning of the wire section of the papermachine. In addition, as Van den Akker pointed out, there seems no doubt that our present concepts of the theory of drainage are soundly based.

Effects of consolidation on the fibres

I HAVE already placed some emphasis on flexibility and conformability of the fibre and will do so again in discussing other aspects of our general theme. It is well therefore at this juncture to bring in the underlying basis not only for such properties, but for virtually the whole of papermaking, that is, cellulose/water relationships.

Christensen & Giertz have given us a well-considered and useful review of the subject, touching on nearly all the important aspects relevant to processes involved in papermaking. They advocate a change from the thermodynamic approach to one that is more mechanistic, involving particularly more extensive direct microscopic observation. These authors have had their advice heeded very rapidly, since one of the outstanding features of this symposium has been the amount of direct observation in the microscope.

Robertson has dealt with cellulose/water relationships through water retention measurements and has been concerned here with those portions of the water held by cellulose fibres in rigid and collapsible pores. These measurements have shown interesting interrelationships with various physical and chemical treatments of the fibres and with fibre morphology.

We turn now to the problem of the effect of consolidation forces on pulp fibres. A large proportion of the material presented at this symposium has been in this field and, taken collectively, this certainly constitutes one of the symposium's highlights.

Stone & Scallan have developed a concept of cell wall structure involving coaxial lamellae. On drying, these lamellae draw together into thicker aggregates, which decreases the pore volume, but leaves the same separation in the remaining spaces. The authors suggest that the true meaning of internal fibrillation is the extent of the surface area in the fibre, representing the number of lamellae in the cell wall and that flexibility and swelling are related in that the flexibility of the fibre should increase as the square of the number of these lamellae in the cell wall.

Van den Akker, Jentzen & Spiegelberg have emphasised the importance of the effects of forces applied in the plane of the web during the various phases of consolidation and have dealt with the effect of drying under tension on individual fibres. The tensile strength and Young's modulus are both increased. Strain hardening and creep are produced under suitable conditions. A sudden extension is obtained shortly after drying begins, before the expected shrinkage to a permanent set. This remarkable phenomenon is obviously associated with a marked reorganisation in the structure and it is to be hoped that more work will be carried out to elucidate further the changes in structure that occur in this region. The increase in Young's modulus and tensile strength on tension drying was ascribed to local readjustments in microfibrils in the S2 layer and to improved alignment of crystallites.

Kallmes & Perez in their contribution on the load/elongation properties of fibres have obtained similar results on the effect of drying fibres under tension. They found that the elastic modulus of freely dried fibres was tripled by drying under axial load and that the tensile strength was increased and the stretch decreased in proportion to the loads applied, over a wide range.

Duncker, Hartler & Samuelsson measured the changes in stress on fibres under load with drying and showed the interrelationships between shrinkage potential and elongation on wetting the fibre under load. Proper adjustment between these two factors produced dimensional stabilisation. The results obtained by these authors on the changes in modulus of flexure with drying are of considerable interest. A very marked increase in stiffness up to a maximum was obtained between 15 and 30 per cent solids content. It is tempting to speculate whether this is the same range of dryness at which Jentzen obtained his sudden extension and whether the two effects are rooted in the same cause —some form of reorganisation in the structure of the fibre.

One of the striking generalities to be drawn from these contributions dealing with the drying of fibres is the marked similarity between the effects produced on individual fibres and the familiar effects produced on drying the paper web. This justifies the conclusion that more information is required on the behaviour of individual fibres during consolidation. It would seem of particular interest to relate the progress of these changes directly to moisture content, as carried out by Duncker, Hartler & Samuelsson in the case of stiffness.

This has been done in one area in the contribution by Tydeman, Wembridge & Page, who have related the shrinkage in width of individual fibres to the shrinkage of the web and found a satisfactory relationship. The progress of the moisture content of the fibres was also measured by the technique used. It is interesting to note that the rate of shrinkage of the fibres in the transverse dimension increased with increasing dryness, similar to the effect long known with paper.

Pye, Washburn & Buchanan have used the scanning electron microscope to follow the effects of successive stages of consolidation on the web, both in handsheets and in three typical grades on the papermachine. The structure was reasonably well preserved by freeze drying in the preparation of the samples. It is tempting here to use the old cliché that a picture is better than a thousand words. There is a wealth of information in these photomicrographs and they warrant in my estimation very detailed study. It is impossible in a few words to discuss this series of pictures in detail, but I was struck particularly by the fact that the fibres show marked changes at a surprisingly early stage in the consolidation process. This is exemplified by many instances of collapse even before the couch, of quite severe deformation in the press section and of apparent closeness of contact of fibres at crossovers, where the moisture content is still very high. I am sure that many of you like myself will now have a somewhat different concept of what the web looks like as we walk from the head box to the calender stack of a papermachine or as we consider some of our problems in the laboratory. It is interesting to note that this important matter of the collapse and conformability of the fibre has received a justifiably good measure of attention in the symposium contributions.

In addition to the photomicrographs of Pye, Washburn & Buchanan, others have discussed the measurement and effect of fibre collapse.

Robertson used the difference between an equilibrium water retention value and the water content at the dye migration end point as a collapsibility index and has correlated this with independent fibre flexibility measurements.

Balodis, McKenzie, Harrington & Higgins measured the behaviour of individual fibres in lateral compression directly and obtained load/elongation and recovery curves, which were then compared with results obtained on various tubular structures. Interesting differences were brought out between dried and never-dried fibres.

Duncker, Hartler & Samuelsson showed not only an increase in stiffness of fibres on water removal up to about 30 per cent solids content, but also a decrease in stiffness thereafter with early wood fibres, owing to collapse.

Effects of consolidation on the web

ATTENTION is now directed to those contributions dealing generally with the effects of consolidation processes on the web in contrast to the effects on individual fibres that have been discussed above.

Van den Akker and his colleagues believe that, in tension drying of the web, there is local yielding in most fibres and bonds that disposes them in the dry sheet in such a way that the elastic modulus and the tensile strength are increased in the tension direction.

Page & Tydeman and Tydeman, Wembridge & Page have discussed the interrelationships between fibre shrinkage and web shrinkage. They came to the conclusion that the potential shrinkage of fibres is large enough to produce the sheet shrinkage observed.

Nordman, Aaltonen & Makkonen have presented a relationship between nterfibre bonding strength and the consolidation of the web, as it is affected by beating and wet pressing. Whereas previous findings by Nordman and his colleagues had indicated that the bonding strength of a given pulp, as measured by optical means, was independent of beating and wet pressing, more recent work had shown that these factors have a definite influence on the bonding strength under certain circumstances, beating being more effective than wet pressing. The interplay among the factors involved are discussed by Nordman in a thought-provoking manner.

Henderson, Barton & Erfurt have shown that treatment of pulp in a disc refiner at high consistencies protects the fibres from gross damage such as cutting, thus preserving the fibre length and tearing strength. The fibres are crinkled and bent and the stretch of the final sheet is increased. Two of the interesting points to arise in this work are the effects of the very high temperature to which the fibre suspension is subjected during the refining and the extent to which the high stretch of the sheet is maintained during tension drying. The flexibility of the fibres should affect the second of these points and further work suggests itself in connection with pulps of different origins. Page presented evidence to show that treatment of pulp by any means at high consistency results in a shortening of the fibres through microcompression, which is subsequently reflected as a higher stretch to break.

Goring has measured the glass transition temperatures of cellulose, hemicellulose and lignin with and without water as a plasticiser. Lignin is shown to be hydrophilic in the sense of the activity of water in lowering this temperature of transition. Of particular interest is the accompanying development of a tack temperature or temperature of adhesion. Goring also emphasised that water cannot be taken for granted and that our normal concepts of water are quite obsolete. Water has a structure that is labile in the presence of cellulose and much interest was aroused by his observations during discussion.

The optical consequences of the consolidation process have been reviewed by Giertz in relation to the changes brought about in the scattering power throughout the whole of the papermaking process, including stock preparation. Giertz emphasised the suitability of light scattering as a means of following the consequences of stages in consolidation and in relation to strength development and sheet structure.

The shear behaviour of fibre assemblies from dilute networks through to the final sheet has been monitored non-destructively and continuously by Craver & Taylor through the application of pulsed ultrasonic shear. This intriguing technique gave results of considerable interest in reproducing the effects of various stages of consolidation in a single sample. The advantages inherent in this method of evaluation of the degree of consolidation in the web are such that it may be expected to be taken up by others and used widely as a research tool.

The course of tensile strength development in the web during consolidation is of particular interest and several contributions have been made on this topic. Robertson has divided this strength development into four regions, as denoted by changes of slope of tensile strength plotted against increasing solids content. The fourth region above 45 per cent solids content represents, he believes, the development of interfibre bonding. This stage of the drying process (that is, at 45 per cent solids) is considered to represent a critical region and a number of important items of experimental evidence are adduced for this viewpoint. Page & Tydeman have concluded from direct observation in the microscope that the final regions of contact or bonding begin to form with an unbeaten pulp at a solids content of 45–50 per cent and note that this takes place before the dehydration and shrinkage of the fibres. This general question of interfibre adhesion before fibre shrinkage and final bonding through the Campbell effect was discussed by me following the paper by Page & Tydeman (p. 393) and need not be summarised here. It is interesting to note that other statements and evidence presented at this symposium have a bearing on this question of interfibre adhesion at earlier stages in consolidation.

The effects of various extraneous additives on the formation and consolidation of the web were capably reviewed by Balodis, McKenzie, Harrington & Higgins, who dealt with hydrophilic colloids and other non-fibrous materials, by Schwalbe, who included sizing, adhesives and fillers and by Swanson, who discussed soluble non-fibrous materials. This group of papers contains a wealth of material impossible to summarise here, but it is obvious that these valuable compendia will be very useful to all of us who are interested in this field both in research and in practical papermaking. It is apparent that all stages of formation and consolidation can be markedly affected by the presence of one or another of these agents ranging from the degree of swelling of the fibres at the outset through to the properties of the dried sheet. Some of the points of interest are the changes brought about in the nature of the fibre surface, the possibilities of bridging between fibres or external fibrils or lamellae and flocculation. Balodis *et al.* have provided an interesting beta-ray scanning method for the measurement of flocculation. There is no doubt that much work is required to clarify many points concerning the effects of additives and the effect on flocculation is a particularly important example of these needs. The volume of discussion that followed these papers attested to their interest.

The forces normally considered in consolidation are all those external and internal forces that are exerted normal to the plane of the web, together with tensile loading in the plane of the web. Compaction may however also be carried out by compression in the plane of the web, leading to extensible or high stretch paper. This procedure was dealt with in two closely allied papers by Ihrman & Öhrn and by Welsh. During the compaction in the wet web state, fibres are forced into closer juxtaposition by partial filling in of previous voids. The fibres become curled and the sheet increases in density. Presumably, as a result of less bonding area, the sheet has a lower tensile strength, but the course of the stress/strain curve is markedly different, yielding a very much higher stretch to break and a greatly increased energy absorption capacity. The latter particularly is of considerable practical importance for certain grades of paper and the basis for the alterations in structure brought about by this type of compaction is important toward further improvements, in addition to filling out our knowledge of all manner of consolidation forces.

Two papers dealing with dry pressing or calendering complete the list of contributions on the effects of consolidation on the web. Mardon, Monahan, Carter & Wilder have examined the mechanism of the calendering action and the relationship between compressibility and various factors such as pressure, moisture content, temperature and time. The behaviour of paper is found to be more nearly plastic than elastic. The relative importance of smoothness and compressibility on printability was also investigated. Parker has examined various factors involved in dry pressing in relation to the physical properties important in suitability for printing, including surface smoothness, opacity and bulk. From the papermaking point of view, one of the most, if not in fact the most important problem in the general field of printing papers is the attainment of the best possible compromise between two apparently opposed properties—opacity and surface smoothness. Although all of the papermaking process is involved in this compromise, these extensions of our knowledge of the effects of the factors entering into calendering and the mechanism of calendering should lend valuable assistance in this important problem.

Structure and properties

We come now to a series of contributions in the last broad phase of the symposium, namely, the consideration of the structure of paper and the relationship of structure to certain properties.

Page, Sargent & Nelson have described an improved technique in the cross-sectioning of paper that should prove useful in obtaining more detailed information in the direct visual examination of the structure. Taylor & Craver have applied the principle of sonic velocity to obtain information on elastic properties of paper such as Young's modulus, shear modulus and Poisson's ratio. It is particularly interesting to note that local variations in structure can be mapped by this technique and the contour lines shown for both handsheets and commercial papers are valuable for their assistance to our concept of non-uniformities in structure in relation to formation and consolidation processes.

In this connection, Norman has investigated the effects of non-uniformities in substance and in what he terms forming consolidation—that is, the manner and extent to which the smaller fibre fractions are packed into available voids. A very interesting by-product of this work is the development of a novel and simple method for the evaluation of the uniformity of formation of paper.

Kallmes & Perez in their second contribution have described a new theory for the load/elongation properties of paper, using an entirely analytical approach. The calculated stress/strain curves were said to be in reasonably satisfactory agreement with those actually measured; the authors note that further development of the theory will take into account the stress/strain characteristics of the fibres themselves and the important factor of fibre orientation distribution. The very spirited discussion of Kallmes' paper was in my view a very useful one in delineating the limitations of a model as a concept or hypothesis and in the presentation of the various points of view involved. Using the multi-planar concept of paper, Corte & Lloyd have defined the pore size in terms of the dimensions of the fibres and of the sheet and have developed theories further for the pore size distribution and the maximum pore size. The pore size distribution was found to be dependent also on the type of fluid flow and the application of the theory to laminar flow gave formal agreement with the Kozeny-Carman equation. Corte notes that further development of the theory relating fluid flow to structure must await an adequate definition of a layer in the assumed layered structure.

In a comprehensive review of the recent literature on the effect of sheet structure on stress/strain characteristics of paper, Algar has surveyed the factors involved in structure, including fibre properties, bonding and sheet geometry, also the existing theories relating sheet structure and its mechanical behaviour. Algar has concluded that none of the theories so far proposed provides an adequate interpretation of the measured stress/strain behaviour. He suggests that the mechanism of bond rupture and the mode of distribution of load among the various elements will have to be taken into account in further developments toward an adequate theory.

A very thoughtful discussion was given to us by Corte on the general approaches to the derivation of the structure of heterophase solids in terms of the dimensions of the constituents and their relative positioning in the assembly. The conclusion was reached by Corte that a number of approaches must be used at present in this problem, in the hope that eventually these may converge toward a central concept of the mechanical behaviour of paper. Mark gave the symposium a very interesting account of the make-up and properties of various synthetic fibres together with their papermaking potentials.

General remarks

As POINTED out at the outset of my remarks, the theme of the consolidation of the web has necessarily and properly touched upon practically the whole field of papermaking. In essence, speaking now from the point of view of application, I would venture to say that we are trying to find the underlying basis for the properties and behaviour of paper, not only to understand what we are doing now, but to produce better paper for a wider variety of applications than we now enjoy.

The properties of paper (to simplify somewhat) depend on the properties of the fibre constituents, on the extent of bonding between them and on their arrangement with respect to one another. In this symposium, we have learned a great deal about the properties of fibres and their behaviour under the influence of the forces of consolidation. The effects of some of these fibre properties on interfibre bonding and on sheet geometry have also been brought out more clearly. Thus, the matter of fibre properties has been given particular prominence as being of outstanding importance. This view is not new, but the further evidence we have heard seems to make it unassailable. We have been shown excellent correlations between the properties of individual fibres and the corresponding properties of the sheet and this is very encouraging. In my view, there has regrettably been one important factor missing in this connection. We have heard nothing about damage to the fibres brought about by previous processing. As a matter of fact, I think I heard this referred to only twice during the whole symposium and that merely in passing. Much work is required in the development of techniques for the recognition, description and measurement of such damage.

We have learned much also about interfibre bonding, its onset and measurement. Here again, I would point out that far too little attention is paid to the question of whether failure under stress actually takes place in the bonded area or whether much of the failure in fact occurs within the fibre adjacent to the bonded area. Cogent arguments can be adduced for such a preferred type of failure in at least some measure and I recall presenting this view a number of years ago. Some of the photomicrographs in recent literature seem to bear this out, but I suggest that a specifically directed attack on this question would be eminently worthwhile. *It may be that the clear distinction we make between fibre breakage and bond breakage is to a large extent unjustified.* Among the other problems remaining in this area, I suggest that the two outstanding ones are the mechanism of bond rupture—intrafibre or interfibre—and the lurking doubt that remains about the identity of optical contact and actual bonding.

On the question of fibre arrangement and sheet geometry, we have been told that a great deal of further research is required before we can confidently relate structure to properties. This suggests strongly to me that, until we know much more still of fibre properties, of such intimate matters as load distribution at sub-fibre levels and the like, we are unlikely to succeed in developing a model that will satisfactorily reproduce the essential properties of the sheet. This is of course not to say that we may not have a concept or a hypothesis; indeed, we would make no progress without one and this concept or hypothesis must be continuously revised in the usual fashion of science. I suggest rather from what we have heard at this symposium that it may be premature to attempt to develop a mathematical model, based on insufficient facts, with all the attendant dangers of the assumptions, fittings and the nimble mathematical juggling required.

The direct approach has, I think, been very noticeable in this symposium. Photomicrographs showing clearly what has happened, compressing and relaxing single fibres directly, direct observations of the layered condition of fibres in the web and of the mode of fibre deposition on filtration, direct observation of optical contact, direct elastic and bending moduli measurements on fibres and other examples illustrate this desirable phenomenological approach. The discussions on each paper have been lively and stimulating, as one would expect from a knowledgeable audience.

Finally, I would like to make one general comment. It struck me, as it must have done you also, that these symposia have offered a remarkable combination of fundamental concepts and specific applications. This, in my estimation, is one of the greatest achievements of the symposium. The organising committee has succeeded in assembling a group of capable men to present research material of a fundamental nature, who are equally capable of interpreting such material in the light of practical problems. I am grateful for the opportunity of congratulating the contributors to this symposium for their excellent papers and the committee on the outstanding success of the meeting they organised so well, to say nothing of their remarkable good influence on the weather.