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TEXTURAL PROPERTIES OF PAPER: MEASUREMENTS AND FUNDAMENTAL RELATIONSHIPS

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Synopsis The textural properties discussed include surface softness and bulk softness in tissues and towelling, handle in printing and writing papers and drape in non-wovens. These properties are discussed in terms of individual measurable factors and complexities are shown. Inadequacies of objective test methods are described and the necessity for subjective judgment noted. A brief account is given of psycho-physics in the field of tactile perception and examples are given of its basis and application in subjective testing. Tactile perception is shown to provide a high degree of accuracy and precision.

Properties, testing and functionality

It is axiomatic that, in order to improve the properties of any given material, as complete information as possible is necessary on two factors—the currently available level of property must be measured in meaningful terms and the basic factors underlying the property in question must be understood in order to give sensible direction toward its enhancement.

These basic and rather obvious considerations hold true for paper as they do for any other material. During recent years, increased attention has been paid to the structure of paper and to the properties of the individual fibres of which the web is composed. As the knowledge of the structure has accrued, attempts have been made at relating structure to properties and it is apparent from a study of the literature, particularly over the past 25 years, that great strides have been made in this direction. Not surprisingly, many gaps in our knowledge still remain. Nevertheless, it seems reasonable to conclude that the composite picture we now have of the web called paper is not seriously at fault and that further intensive research will assist materially in extending this knowledge, hence the breadth of application of paper, but is unlikely to change our present concepts seriously.

Under the chairmanship of Dr J. D. Peel

Most of the paper made is used for two purposes—for the packaging of other materials and as a substrate for the carrying of a message through printed or written characters or designs. The functional characteristics of the paper for any one of these purposes are assemblies of readily conceivable individual properties. In packaging, for example, we obviously must have certain physical properties such as tensile, bursting and tearing strengths or stress/strain at certain desirable levels. In addition, it is frequently required that the paper be resistant or proof to a variety of liquids, vapours or gases. In many instances, the paper used for packaging serves also to carry a printed message, so that there is a direct overlap with some of the properties required in printing and writing papers. In some instances, the paper might be a part of a laminated assembly with other materials in order to attain the desired properties.

In printing and writing papers, the usual strength properties are of quite secondary importance, provided they are kept above a reasonable minimum. Such properties as ink receptivity, faithfulness of reproduction through surface smoothness, opacity and the like become of major importance. With some systems of modern reprography, the electrical properties of the paper assume great significance.

In general, a number of the properties that are required for some of these papers cannot be obtained from the cellulose web alone, but must be attained through the addition of extraneous materials. In recent years, this has been one of the most active fields of development in paper. It has indeed emphasised one of the more serious gaps in our knowledge—the surface properties of the fibres that have a bearing on the interrelationship with added materials either within the web or on its surface.

In general, the measurement of the properties entering into the functionality of papers for their many uses has served the situation well. Most of them are pragmatic and seemingly direct in relation to the information required. This is not to say that the phenomena underlying the tests are thoroughly understood. On the contrary, our knowledge in this area is rather limited. Even tensile strength, probably the simplest of the physical strength tests, is seriously lacking in this respect. There is considerable doubt about the roles played by fibre failure versus interfibre bond failure. Other physical tests like folding, tearing or even bursting strength are obviously much more complicated. These tests are arbitrary and must be carried out in a standard manner, otherwise results will vary for a variety of reasons. It is in general realised that, for many functional uses, results obtained at the failure point in a physical test may be of much less interest than the manner and extent of the strains produced in the paper at lower levels of stress.

Measurements of optical properties such as opacity and brightness are direct and meaningful, although again arbitrary with specified parameters. The velocity of moisture imbibition and the waterholding capacity of bibulous papers are measured in direct manner, as are also water and grease resistance and the like. The same holds true for a number of miscellaneous properties such as dimensional stability and surface smoothness.

Through the gaps in our knowledge of certain features of paper structure that constitute the underlying basis for these tests are still in the main extensive, nevertheless the objective testing of paper has proved invaluable and absolutely indispensable for the orderly advance in the improvement of paper for its traditional uses and the rapid extension of the uses of papers in newer applications.

Subjective testing

A FEW properties of paper have not, however, been successfully measured by objective standardised testing and the following discussion deals with several such properties.

Among these, the outstanding properties are bulk softness and surface softness, particularly in tissues and what has been termed *handle* in the case of printing and writing papers. With the advent of non-woven papers, the draping properties become of importance. In towelling, a clothlike feel becomes a major feature.

No objective methods of measurement available here are truly adequate and recourse is made to purely subjective testing, often by a carefully chosen panel, following a carefully designed technique of comparison rating, with eventual numerical values assigned on one basis or another.

The testing is therefore carried out by tactile perception. In the field of psychology, a study of the literature shows a large measure of neglect in this area. Much more has been done with other sense perceptions, particularly with sight, but also with hearing, smell and taste. Volumes have been written on the details of sense perception with the usually considered sense organs based on a tremendous amount of experimental work and extending also into the field of neuro-physiology. In comparison, the field of tactile perception has been relatively neglected.

Some of the basic considerations in psycho-physics as related to tactile perception are of considerable interest. It is not customary to think of the hand as a sense organ; we think of it in the main rather from the point of view of performance through holding or manipulation. Nevertheless, if we consider the situation a little further, it is clear in fact that we do use the hand for exploratory purposes in a variety of ways. These include, as examples, the measurement of temperature, the perception of shape, size, weight, dimensions, consistency, texture and the like. This perceptual capacity of the hand is of course brought sharply to the fore in the dark. The blind develop and use tactile perception to a high degree in the absence of visual perception. A clear distinction can be made between static and dynamic touching. The latter gives much more information in perception and the tactile perception used for testing usually involves the movement of the fingers. It is probable that not only the skin, but joints and muscles are involved in the process in many instances.

An interesting generalisation in this field of psycho-physics has now been widely accepted for all human senses. Perception is related to the stimulus by a power function—

$$I\text{ (perceived)} = kS^n$$

$$\text{or } \log I = \log k + n \log S$$

where I is the intensity of sensation, S is the intensity of the stimulus and k and n are numerical coefficients.

The coefficient n will vary, depending on the human sense being employed and the type of sensation perceived.

This generalised power law has been shown for vision—for example, darkness/light, for the sense of smell, for the sense of hearing and for taste. In recent work, it has been shown that this generalised law in psycho-physics holds also for tactile perception and an example is shown in the next section.

Surface softness

For such papers as bathroom and facial tissues, also certain kinds of napkins, softness is of paramount importance and a reasonably clear distinction is generally made between bulk softness and surface softness. These are dealt with separately in this discussion.

The surface feel desired is similar to that obtained from velvet. A smooth surface, like that of a thin fruitwrap, gives a feeling of slickness and hardness rather than of softness. Irregularities or projections on the surface are required, but these must have certain properties. A creped tissue made preponderately from mechanical pulp feels rough, approaching the feel of a fine emery cloth.

In the making of dry creped tissues, the drying takes place on a single Yankee dryer and the degree of adhesion to the dryer at the point of take-off by the creping blade is carefully adjusted. A considerable degree of delamination and distortion takes place within the sheet and fibre ends project from the surface. After light calendering and draw to the reel, the sheet retains 15–20 per cent residual stretch in the machine-direction. The angle and other details of the creping blade, as well as the dryness of the sheet and degree of adhesion to the drying drum at the point of creping, are important factors in the surface and bulk softness of the tissue.

Many attempts have been made to measure surface softness of tissues quantitatively by various objective means. These have included coefficient of friction, sound produced by moving a tissue surface against adjacent surfaces of various kinds, etc. None of these attempts has resulted in measurements of value or interest.

In the author's laboratory, some unpublished work was carried out some years ago on the relationship between the number of fibres or fibre bundles protruding from the surface of a tissue per unit area, with the subjective judgment given by a test panel. A general tendency to a relationship was found. Undoubtedly, this was disturbed greatly by the length of these fibres or fibre bundles protruding from the surface and the variation in their degree of flexural rigidity.

When this very important property of surface softness is measured, a test panel is used and ratings are assigned to this property. Tactile perception, exerted through the movement of the fingers lightly over the surface of the tissue, is very sensitive in the measurement of the resistance to deformation offered by these irregularities on the surface. If there is an insufficient number of them or if they are too rigid, the perception is that of an undesirable surface feel in this context and the interpretation is that of a slick or rough surface, respectively.

The accuracy of tactile perception is well exemplified in the following series of experiments.[1] A panel of non-experts made judgments of the degree of roughness of a carefully selected series of 12 emery cloths of graded grit numbers ranging 24–320. No vision was involved, leaving a purely tactile perception. The subjects were instructed to draw the index and middle fingers of one hand twice across each surface as it was presented. In one series, one of the emery cloths was presented as a standard with an assigned roughness number and the others were judged against it. In the second series, the subject set his own standard with the first emery cloth presented to him. In a third series (cross-modality), the loudness of a noise was matched to roughness. All three series were repeated with judgment of degree of smoothness rather than roughness.

A number of interesting results emerged. The power relationship referred to above was found to hold for both smoothness and roughness, the slope of the log-log line being 1·4; the precision was about the same for smoothness and roughness. This is a particularly important factor. The cross-modality when roughness or smoothness was matched against loudness of sound also showed the same result. A particularly interesting point arose when a slight anomaly appeared in the position of one of the points on the graph. On closer examination, it was found that the emery cloth in question had the grit particles less deeply imbedded in the substrate. This led to a qualitative difference, since the shallower immersion of the grit particles in the bonding adhesive in this one case led to a slightly different order of skin catches than with the more deeply imbedded one. The results were plotted in estimated magnitude of roughness (or smoothness) against grit number, which in turn is roughly proportional to the reciprocal of the grain diameter of the grit.

Thus, a quantitative relationship was shown to exist between tactile perception and a specific physical property of the paper that is known and measurable in actual numbers representing physical dimensions.

This is a relatively simple example of the surprising degree of accuracy and precision to be obtained in the judgment of surface roughness. It represents a rigid system of spaced irregularities of different diameters. The case of the tissues is much more complicated in that there is not only an integration of the number of irregularities and their flexural rigidity, but it is altogether likely in addition that the factor of compressibility of the tissue itself plays a part.

Since no basis for a comparison of tactile perception with any directly measurable physical units is possible in this area of surface softness, no judgment can be made of the accuracy of the test as was possible with the emery cloths noted above. Nevertheless, long experience in many papermills has shown that this subjective test is capable of a high level of precision. For practical purposes, it is obvious that an objective test by instrument would be highly desirable, but this has not yet been attained.

With paper towelling, although the chief properties of speed of liquid imbibition, liquid-holding capacity and wet strength are basic to functionality, yet the surface feel of the paper has become an important factor in marketing. Here, a clothlike feel is required, reminiscent of the textile towels they replace. The cotton towels consist of fibres that are woven and therefore possess a large degree of freedom of motion under slight pressure. Tactile perception therefore gives the interpretation of softness of surface. With paper towelling, entailing individual fibres of high stiffness that are bonded to one another at frequent intervals, the grammage required for functionality produces a material of low compressibility and a feeling of hardness. An approach to a woven feel is attained by a suitable embossing of the surface, but the hardness still remains. This defect is overcome by a build-up of two plies of towelling, so arranged in the embossing and assembly, that regularly spaced small voids are provided for in the structure. This adds greatly to the compressibility. In many varieties of modern paper towel, by means of a correct embossing pattern and the proper assembly as noted above, a remarkably good approach to a clothlike feel is attained.

Here again, no means of objective measurement is available to measure this surface feel and recourse must be made to tactile perception by a panel of judges.

Softness

SEVERAL authors[2, 3] in this field have noted the difficulty of defining softness and the various individual physical properties that play a part in softness. These include density, flexural rigidity, compressibility, resiliency and surface smoothness. This is not a matter of surface softness (which is the opposite of hardness) or of resistance to indentation by another material. The softness under discussion is rather that exemplified by the ease of crumpling.

For the making of soft tissues, a large proportion of long-fibred softwood should be used, since the pulp remains unbeaten. Interfibre bonding must be reduced to the minimum consistent with strength required for ordinary usage in order to attain softness and avoid flexural rigidity. During the early part of a beating curve, the stiffness of the paper increases markedly with the introduction of further bonding. The optimum relationship between softness and strength is attained by creping off the Yankee cylinder. As noted in an earlier section, the various factors affecting creping are of substantial importance in attaining the desired result. The degree of adhesion of the web to the drying cylinder and the extent of subsequent pull-out of the crepe are important. The tensile strength at failure is generally reduced to a considerable extent and an elongation of the order of 15–20 per cent is normally required. The shape of the stress/strain relationship is thus markedly altered. The energy absorption capacity is increased and the thickness is increased as might be expected with pull-out. Physically, creping exerts quite drastic changes in the structure of the paper, including folds involving the whole thickness and in particular a significant degree of internal delamination and fibre rearrangements.

Softness and strength are opposing properties. No matter what means is applied to increase softness (for example, creping, use of surface active agents, so-called softeners such as glycerine or sorbitol), an improvement in softness is always accompanied by a loss in strength. This is attributable to a decrease in the amount of interfibre bonding per unit area.

Of the various individual properties that enter into softness, there is no doubt that flexural rigidity is the most important. This is indicated by the fact that the objective testing of softness is now carried out with instruments that measure flexural rigidity. It is apparent that increased interfibre bonding reduces the free fibre length, therefore the ease of bending of the whole structure.

From elementary mechanics, the flexural rigidity is proportional to the product of the modulus of elasticity and the moment of inertia. Since the latter involves the third power of the thickness, the bending stiffness should vary as the thickness cubed. This has been shown for paperboard.[4] In other instances, the power factor has been noted as somewhat less.

A number of instruments have been used for the measurement of flexural stiffness, which is frequently and loosely used as a measurement of softness. These have all been described repeatedly in the literature and need not be detailed here. Comparisons have also been drawn among them.[5]

These instruments, with one exception, are based on the cantilever principle, in which either the curvature formed by the paper under its own weight is measured when the strip is held at one end or the deformation is measured when a force is applied. In another type, the critical length of paper is measured that causes the strip to flop over from one side to the other when the carriage is rotated through 90°.

One instrument that is somewhat different in principle is the Handle-O-Meter. This has been widely used as a control instrument in papermills for the measurement of softness. Here, the force required to bend the sheet is measured, but in a somewhat different manner. The tissue is placed on a smooth metal plate so that its centre lies across a narrow slot extending across the plate. A narrow bar is lowered automatically through the slot against the resistance of the paper. The force exerted on the bar as it descends is sensed by a strain gauge mounted on the beam holding the bar and is registered on a meter. The force increases initially followed by a decrease and the maximum reading is taken as the stiffness. It is possible that the surface roughness plays some small part in this case, in addition to the flexural rigidity.

The principles of fundamental mechanics have been applied somewhat loosely to paper, since the latter is not homogeneous and has only a very limited range of elasticity, after which the stress/strain curve shows plasticity. It is interesting to note, however,[6] that the Handle-O-Meter stiffness and the elastic modulus determined by torsion were compared on synthetic films with good agreement.

The results obtained with objective measurements by instrument compared with the comparative ratings assigned by subjective examination, are inadequate, particularly when the level of softness is high. It is apparent that the properties other than flexural rigidity, detectable by subjective means, are insufficiently taken into account in instruments measuring essentially only the one property of flexural rigidity. It is interesting to note, for example, that with two papers having the same flexural rigidity but differing in thickness, the thicker paper will feel softer. It would appear that this is based on the added factor of the greater compressibility of the thicker paper, other factors being equal.[7] The stress/strain relationship in thickness is important, since two papers might be reversed in order of thickness as the stress is increased.

Softness commonly increases with extensibility, presumably owing to the greater disruption of interfibre bonding involved.

Subjectively, tissue softness is frequently measured by crumpling a given area of tissue in the hand. From the point of view of the integrated processes leading to perception, this type of stimulus is obviously much more complicated than that of the finger tips judging surface softness. The stimulus here is the resistance of the paper to a very extensive bending deformation in all dimensions and directions, including the thickness dimension and a twisting and compression in the plane of the paper. The muscles, tendons and joints are involved in this tactile perception rather than sensory points on the skin and the total work expended is judged. It would appear that no quantitative work has been carried out in this area, but, judging by analogy (say, in the lifting of weights), here also the perception is related to the stimulus by a power function.

One relatively primitive approach to an instrumental measurement of softness that departs from straightforward flexural rigidity was made in the author's laboratory some years ago.[2] Two plies of tissue were constructed into a cylinder by wrapping around a mandrel, spot glueing the free edges with a flexible cement and removing the mandrel. The upright paper cylinder was loaded at a constant rate by a sensitive device and the load that produced crumpling was noted. The end point is quite sharp. This instrument included the factor of compressibility in measuring a modulus of collapse. It must include also a function of surface softness, since it is impossible for the cylinder to crumple without a slippage between the two layers comprising the tissue cylinder.

This instrument, although obviously only a very simplistic approach to a crumpling of a sheet in the hand, showed much better agreement with the subjective judgment of expert appraisers than an instrument measuring essentially flexural rigidity alone.

It might be speculated on this basis that a 'mechanical hand' might be constructed that would be so constructed as to exert movement closely imitating the hand in crumpling a given area of paper. The force exerted in carrying this out could be measured by sensitive sensors. So far as the author is aware, this kind of more sophisticated approach has not been considered, but it would appear to have merit as a possibility.

An interesting example of tactile perception for the subjective measurement of softness in another area has been reported.[8] In this, the ability of wool graders to judge the softness of an untwisted rope of fibre from a fleece (wool top) was determined. The quality of softness in this material is generally accepted to be directly related to the fineness of the fibres and largely determines the value of a fleece to the wool industry. The normal procedure for test is subjective, in which the visual appearance is combined with the pulling of a strand through one hand. A grade is assigned based on the combination of these two perceptions. In the experiments on purely tactile perception, the subjects were first required to feel the wool tops without being able to see them; in a second series, they looked at them on a black background without being able to feel them. The tactile judgment of softness was in remarkably good agreement with the visual judgments. This was not a matter of expertise in this area. It was found that non-professional unpractised observers using this method of dynamic touch without visual aid gave spontaneous judgments of softness approximately as well as experts.

Handle

THE so-called handle of paper is analogous to the 'hand' of a textile fabric. It applies to a wide variety of printing and writing papers and is the result of a subjective test. The experienced evaluator feels the sheet, squeezes it, rattles it and frequently flexes the sheet into compound curvatures with accompanying relatively sharp folds at angles to one another in the sheet. He may note the hardness and compressibility and always takes into account the resilience of the sheet following a bending deformation. Certainly no standard procedure is followed. This is not a matter of a panel judgment by the customer or consumer, but a highly individualised subjective testing. Nevertheless, experience has shown that, whereas some individuals may favour certain particular characteristics, in general there is a good degree of uniformity of opinion among these experienced observers. These subjective evaluations are of great importance in the acceptance or rejection of paper in the first instance, quite apart from functionality during actual usage.

The evaluator renders his verdict in terms of *body* or *guts* or *character* of the paper in question. Even the highly experienced evaluator has great difficulty in analysing the factors that enter into the judgment he reaches.[9] Several of the factors entering into this integration seem quite clear. There is no doubt that rigidity is the most important. In addition, the feeling of thickness is important—for example, if a paper of x g/m^2 feels like a paper of grammage $x+10$ g/m^2, then this adds to the property of body. Generally speaking, a hardness of surface is also sought. The amount of rattle on shaking or vibrating the paper adds to the impression of resilience and toughness and absence of limpness.

The literature on this subject has been well reviewed by Brecht,[10] who also carried out an extensive investigation comparing subjective evaluation and combinations of individual properties measured objectively by instrument. In this, a series of papers were evaluated by a large number of experts at different locations. These papers were then tested for a variety of properties and correlations were made. The properties included smoothness, hardness, flexural rigidity, resilience in bending, bursting strength and stretch during burst. Flexural rigidities were carried out at various angles.

Of the various correlations made, he found the best to be one with—

$$\frac{(\text{Flexural rigidity})^2\ (30^\circ\ \text{angle})}{\text{thickness}}$$

This is for papers of the same grammage.

It is somewhat difficult to interpret this correlation in its entirety. There is no doubt concerning the primary importance of the stiffness in flexure and this is emphasised by the second power of this property in the correlation with handle for any given thickness. The formula of Brecht, however, also states that, for any given bending stiffness, the handle varies inversely with thickness. This might be interpreted as handle increasing with hardness and this is undoubtebly broadly true, if we compare a distinctly soft paper with a hard paper, both of the same grammage. When the difference in hardness is great, there is no doubt that the somewhat thinner, but distinctly harder paper would be chosen by the appraiser as being superior. On the other hand, some evaluators stress bulk (inverse of density) in judging reasonably similar papers and this emphasis on thickness suggests that the relationship given would not satisfy such observers. Here, we encounter the problem of individual interpretation.

It is particularly interesting to note Brecht's finding that his expression S^2/t (where S is the flexural rigidity and t is the thickness) is quite analogous to S itself in its relationship to the extent of beating. In both cases, there is firstly an increase with moderate beating, then a decrease at higher levels of beating. With stiffness, this is generally interpreted to mean that the stiffness increases with increased interfibre bonding in the early stages. At the same time, the thickness decreases and eventually the stiffness must decrease, since it varies as a power of the thickness. The handle of the paper follows a similar course with beating. When it is further considered that the hardness varies inversely as the thickness, the relationship becomes very involved and further knowledge is required. The careful work of Brecht with its numerical, albeit empirical, expression of a complex subjective property of paper has constituted an important advance in our knowledge of the subject.

Drape

WOODPULP fibres are short and relatively rigid. The paper made from them will vary considerably in softness as discussed above, but even the softest of the papers produced drape very poorly in comparison with a woven fabric.

With the advent of the non-wovens (which must be classed as papers), the subject of draping quality assumes great importance as a physical property. The application of such a material to apparel, for example, requires a very low flexural rigidity, so that the material drapes over contours by its own weight.

The non-wovens using longer flexible fibres with relatively few crossover points and low relative bonded area constitute a usable approach to the draping qualities of a non-woven fabric. Freeston & Platt[11] have given a theoretical analysis of the effect of the diameter, tensile strength, stiffness and distribution of fibres and the density of the web on the flexural rigidity of non-woven fabrics. Using a unit cell model, a methodology was developed for the quantitative prediction of flexural rigidity based on these theoretical analyses. The validity of the mathematical derivations were shown by comparison of the predicted and observed values.

In general, draping quality is measured subjectively, commonly by drawing the web through the aperture formed by touching the thumb to the index finger of one hand. This procedure has been made quantitative[12] by measuring the force required to pull a sample through a polished metal ring at constant speed. The greater the force measured, the greater is the resistance to draping and the poorer the conformability.

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Transcription of Discussion

Discussion

Dr J. E. Luce Dr Hollmark, you mentioned that your signal was a derivative signal, from which I gather that you used a velocity-sensitive phonograph cartridge. I suspect that several other people here have gone through an exercise much like this. They may agree with me that you may have made signal processing a little difficult by starting with a derivative signal of this kind. This entire subject is delicate, because many who have investigated this type of instrumentation wish to say nothing about it at all. I would like to ask if anybody else has any experience in this area, but I am afraid that I would hear only a very loud silence.

Dr B. H. Hollmark We have tried both the simple way described (the derivative taken from the cartridge used) and we have also tried to integrate the signal electronically. In fact, we found little difference between these two approaches, probably because it is overshadowed by so many other factors, mechanical as well as electrical variables.

Dr W. Gallay I have two comments on the remarks made by Dr Hollmark. In view of the modern day requirements for very high bulk softness and the lack of sensitive methods of measurement of stiffness at the correspondingly low levels of stiffness, I doubt very much whether we can depend on this property for the evaluation of bulk softness. Other physical properties, involving even coefficient of friction, are also involved.

My other comment relates to Dr Hollmark's mechanical finger tip. I want to point out here that, if such a general principle were applied to the measurement of bulk softness, we would have to take into account the energy expended by muscles, tendons and joints. In my written paper, I have suggested the notion of a mechanical hand that might measure the work done in crumpling the sheet of the tissue concerned.

Mr B. Radvan I think we must be getting very close to the theme of the conference, because the subject of commercial security came up twice within a very short time!

Under the chairmanship of Dr J. D. Peel

I was very intrigued by Dr Gallay mentioning that it is possible to obtain an appreciable degree of Z-direction orientation. Without saying how it is done, can you tell us how definite it is that such orientation is obtained and to what extent?

Dr Gallay Dealing first with machine-direction and cross-direction orientation, it would appear obvious that we should have a maximum of orientation in the machine-direction. In this way, we would have immediately a very low value for stiffness in the machine-direction and would probably obtain an optimum degree of disruption and delamination on creping for very low stiffness in the cross-direction, together with extensibility in the sheet.

I have no definite information about orientation in the Z-direction, although I suspect that some resides in confidential files of some tissue manufacturers. A good deal of work has been done on the speed of water removal just after the slice and it is interesting to speculate that, under the head box conditions and consistencies that obtain for tissues, a proportion of fibres might in fact be consolidated in the first instance at a considerable angle to the plane of the web. If this were so, one could consider that an effect akin to needling would be obtained in some measure. In such a structure, following the completion of the consolidation by pressing and drying, a substantial difference in the reaction to creping and subsequent calendering might be expected, with an improved compromise of properties in the final sheet. By this, I mean a very high degree of disruption of the sheet, together with an adequate residual strength for ordinary usage.

Dr K. Ebeling Dr Hollmark, why do you call the other property surface softness? It seems to me that it would be more appropriate to term it surface smoothness.

Dr Hollmark No, I think that surface smoothness is quite another property. I would like to draw your attention to when we have a perfectly hard and smooth surface, like polished steel or glass. Then, with the method that we have used, there would be zero peak height and zero peak number, so the ratio is not meaningful. We could interpret this to mean that such a surface has no softness at all, which could be justified I think, because we found from the subjective ratings that these kinds of surface (which were also included in the experiments) had a very large spread compared with ratings for ordinary surfaces—tissues and the like. This could mean that many people cannot distinguish between smoothness and surface softness.

Dr D. H. Page There is a phenomenon that I observed some long time ago, which I assume is well known by the manufacturers of tissue, though it has never been mentioned at any of the meetings I have ever attended. Is it recorded in the literature or is it one of those things that is kept confidential?

If you examine a thin tissue under a low power microscope, the wire mark can be seen so strongly that there are holes in the sheet. When you shear such a sheet, the material between the holes can deform by bending, so that the shear modulus is very low. This does not happen in a sheet of normal grammage. This must surely be a major mechanism contributing to softness in thin tissues. I have a feeling that those who make this grade of tissues know this very well and they know exactly what kind of a wire to use to get exactly this result. Is this a well known phenomenon?

The Chairman There is considerable secrecy (as was implied by another speaker) about these properties, particularly for tissues.

Mr Radvan Yes, this is a known effect. It is now done purposely for tissues, but I wonder whether the original effect was an accident arising from pressure formation at very low grammages.

Dr Page Is any attempt made to optimise the size of the wire mark? You could compute what mesh and weave of wire needed to get the best effect. Do you know if that has been done? Has this effect been published for paper or is it just part of the expertise of a tissue mill?

Mr Radvan I cannot really claim any expertise whatsoever. Perhaps others could answer.

Mr J. D. Hall There are certain North American patents relating to these holes in conventional tissue products.

Mr A. Brucato I want to ask about the apparatus for testing softness. What was the tissue backed with? Is the apparatus moved along the tissue to make the measurement? In which case, the stylus would be moving up and down.

Dr Hollmark The backing material is a sheet of rubber, but I cannot answer today how hard it is. The sample is lying on the turntable, so a mean value of the machine and cross direction figures is obtained. We could place the sample on a rotating drum, but we found that the mean value we obtained with the turntable was quite satisfactory for us.

Mr Hall It seems to me that Dr Hollmark's mechanical finger is like measuring the frequency and amplitude of the crepe. How does he reconcile this with what we consider to be the very important feature of softness, the velvetiness of the nap as mentioned by Dr Gallay?

Dr Hollmark I would probably be supported by the fact that we have incorporated many other materials than tissues. Of course, our interpretation cannot be the whole truth of what is the perception of surface softness. There are, of course, other factors contributing to the feel of softness, but I believe we must start in the first place with this kind of approach.

Dr J. E. Luce I would like to enlarge on my previous comment. Anyone who has worked with tissue recognises that surface softness is related to the projections from the surface—that is, the number of fibres that project from the surface, the height to which they project and the ease with which they can be deformed.

An instrument that is going to measure surface softness successfully should be able to take these three things into account. It should be able to measure the force required to deform the surface projections. If the principle of your instrument is what I think it is, it may simply be a profiling instrument and, as someone else noted, it may be measuring primarily crepe contour.

Dr Hollmark I hope it does not, because we incorporated in the mechanism a spring and dashpot whose properties we could vary extensively. The elasticity and damping of the stylus will, I think, take into account the mechanical deformation of fibres caused by the stylus.

Mr C. E. Dunning Has Dr Hollmark any estimate of the force supplied by the finger in the testing device that he uses?

It is good that you are working with not just a narrow band of conventional creped samples, but that you have structured the curve for a lot of materials other than tissue. I am interested to know the identity and placement of the particular samples around the curve that you have drawn.

Dr Hollmark We estimated the finger force at 5 g per finger.

If I remember correctly, the samples with the lowest softness were some very rough textiles—Indian cotton or something similar—and the highest softness was a piece of velvet. Then we have everything in between—leather, textiles, non-wovens and other kinds of paper samples.

Prof. D. Wahren We were very well aware of the importance of nap and I think it is included in our measurements, because we discriminate in the signal. Actually, the weight of the pick-up is borne by the nap. If there is not a nice nap, the weight of the pick-up will push the sensing stylus down into the base structure. Then we get a signal indicating the opposite to surface softness. So it is included in a way.

The Chairman I think this has been quite an interesting discussion, even without revealing many state secrets, also to see the similarity between these synthetic finger measurements and those with a formation meter.

Prof. Wahren One measures the mechanical properties, the other does not.

The Chairman I meant that they both involve similar mathematical analysis of fluctuating objective properties carried out to match subjective assessments.