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THE SOFTNESS OF HOUSEHOLD PAPER PRODUCTS AND RELATED PRODUCTS

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Synopsis The results of psycho-physical scaling experiments have shown that a property such as softness can easily be scaled like other subjective variables such as loudness and brightness. They have also shown that bulk softness and surface softness should be treated separately.

In search for physical measurements correlating with the subjective properties, one has to proceed along slightly different pathways. For bulk softness, a known physical property—bending stiffness (or, more correctly, inverse bending stiffness)—has been chosen as a good substitute for subjective bulk softness.

An instrument using a 'synthetic fingertip' has been developed for measuring surface softness. The basic principles of the system, as well as recent experimental results are reported.

Introduction

HOUSEHOLD paper products (HPP) and other paper grades whose marketability is at least partly governed by softness are the concern of this study.[1] Papermakers are at present without an objective test for the psycho-physically determined property or group of properties that are referred to as softness. Therefore, the object of this study is to offer a definition of softness that is relevant to the papermaking process and to delineate and measure the properties making up the sensation of softness.

Definitions

SINCE variation in perception is inherent in human judgments of properties such as relative softness, it is desirable to define softness in terms of the mean estimation of a representative population of subjects. Results obtained with an apparatus designed to measure softness should agree with the fundamental human sensation as expressed by the mean estimation.

For this purpose, a psychological scale was constructed by use of a magnitude estimation method. Subjects were presented with various samples

Under the chairmanship of Dr J. D. Peel together with a standard. The standard paper was arbitrarily designated as number 10 on the scale and the subjects were asked to number the other samples in relation to the standard.

Selection of a representative population was attempted by equal sampling of members of both sexes in a range of occupations: 32 people participated in each poll and, all told, 7 680 judgments were made. Each data point on the attitude scales presented in this work represent 128 judgments on the average.

It is generally accepted that the softness concept consists of several components. This work has shown that two components are predominant and, to a degree, independent of one another: they are termed *bulk softness* and *surface softness* and their definitions are suited to practical methods of performing subjective judgments about them.

Bulk softness is defined as the perception of softness obtained when a sheet of paper is crumpled between the hands; surface softness is defined as the sensation of softness when fingertips are lightly brushed over the surface of paper that has been lightly restrained.

Results and discussions

Subjective measurements

THE bulk softness and surface softness can be scaled like other subjective variables such as loudness and brightness.

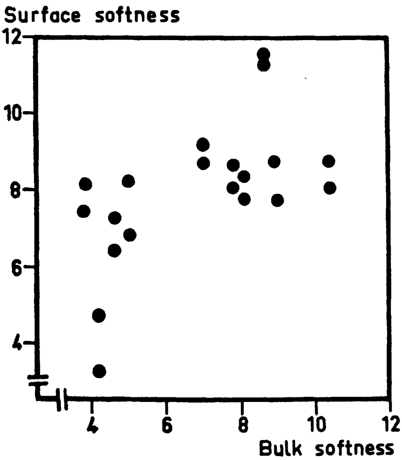

Fig. 1—The relationship between bulk softness and surface softness; correlation coefficient = 0·55

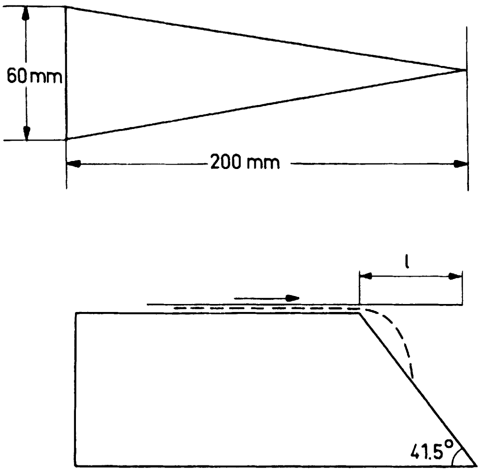

Fig. 2—Stiffness test method SIS 65 00 43 Dimensions of specimen (upper part) and side view of test table (lower part)

The scales of both types of softness are influenced to a minor degree by audio-visual cues. The subject tends to give slightly different statements if he is permitted to see the sample and/or hear the sound it makes when he touches it. This influence is not serious, however, since the correlations between bulk softness and surface softness with and without audio-visual cues are 0·94 and 0·96, respectively.

The relationship between bulk softness and surface softness is shown in Fig. 1. Since the correlation coefficient is 0·55, the assumption that the two properties are interchangeable is not warranted. Therefore, bulk softness and surface softness are maintained as separate concepts.

Physical measurements, bulk softness

A conventional stiffness test afforded the highest correlation of any physical test with subjective measurements of bulk softness. Standard test method SIS 65 00 43 for measuring the stiffness of textile materials was found to be most suitable for this study.

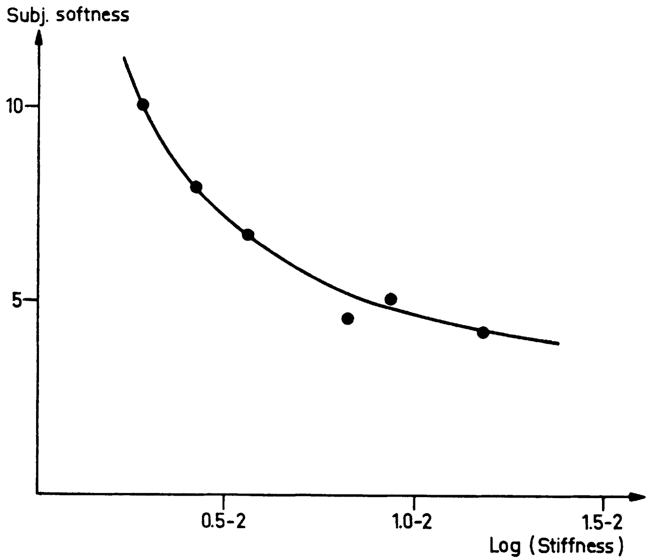

Fig. 3—The relationship between subjective bulk softness and the logarithm of the bending stiffness

In this test, a triangular specimen (Fig. 2) is extended, point first, over the edge of a flat table. The extension is read when the point of the triangular sample reaches a plane that creates an angle of 41·5° with the horizontal. The geometry of the specimen and table is such that the bending stiffness ($E \cdot I$) can be easily calculated from the extension l with the following formula—

$$E \cdot I = \text{const.} \cdot l^3 \cdot W$$

where W is the grammage.

A plot of the logarithm of the geometric mean of machine and cross direction values of bending stiffness against the subjective bulk softness is shown in Fig. 3. The logarithm of the same bending stiffness values are also plotted against the logarithm of the bulk softness in Fig. 4. A power relationship is suggested in the latter graph. Work is continuing with the intention of supporting this relationship.

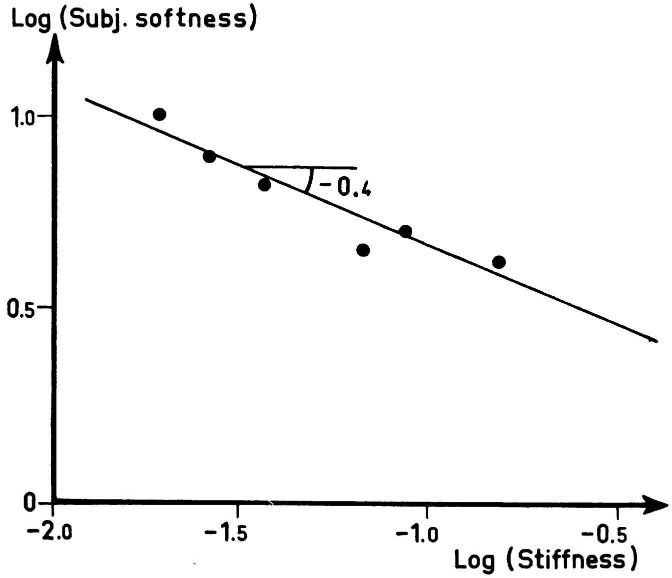

Fig. 4—The same relationship as Fig. 3, although the logarithm of the bending stiffness is plotted against the logarithm of the subjective bulk softness; correlation coefficient = 0·96

Alternatively, the method schematically pictured in Fig. 5 can be used under certain circumstances as a good measure of bulk softness. It is a modification of a method described by T. M. Brown[2] and is similar to the procedure in the corresponding subjective test. The paper is crumpled and subjected to light pressure in the confines of a beaker. The resulting bulk and the applied pressure are recorded and converted into softness by the following formula—

$$\text{Softness number} = \frac{h \cdot P}{100 \cdot W}$$

where h is the height of the piston at the applied load P and W is the grammage.

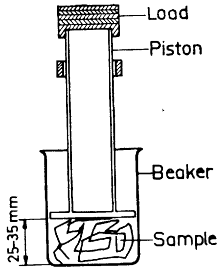

Fig. 5—Alternative physical method for testing bulk softness

The sample is compressed in the beaker; the height (between 25 mm and 35 mm) and the applied load are recorded

For conversion to softness number, see text

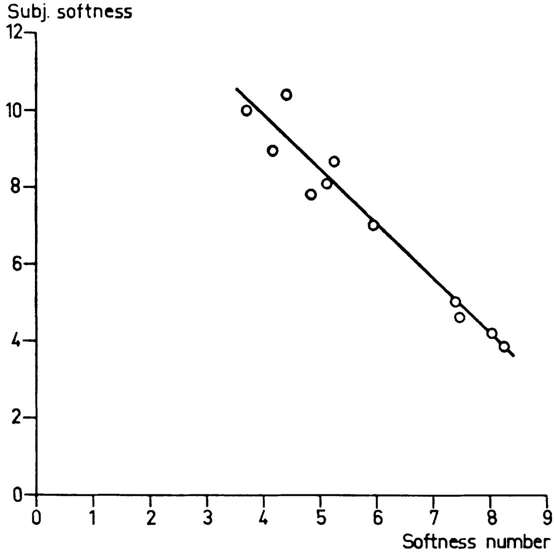

Fig. 6—The relationship between subjective bulk softness and the softness number determined according to Fig. 5; correlation coefficient = 0·97

The softness number obtained with this apparatus is plotted against the subjective bulk softness in Fig. 6 with a resulting correlation coefficient of 0·97. Round-robin tests with this method, however, showed that a considerable spread could exist between laboratories. This was attributed to the rather indefinite way in which crumpled samples are placed in the test beaker.

Tensile strength, stretch at rupture, Handle-O-Meter tests, surface profile data and friction measurements showed weak or non-existent correlations with the subjective bulk softness.

Physical measurements, surface softness

The instrumental evaluation of surface softness is much more difficult than is the case with bulk softness. The surface softness is a complex function of the surface contour and the mechanical properties of the sheet material. The application of the synthetic fingertip shown in Fig. 7 currently being studied is a modified gramophone cartridge. The stylus tip is a cone-shaped piece of steel with a cone angle of 120°. This emerges through a hole in the rectangular base plate. Variables in the mechanical construction are— shape of the stylus (for instance, radius of curvature), extension through the hole, shape of base plate, load on the base plate, elasticity and damping of the stylus, scanning velocity, etc.

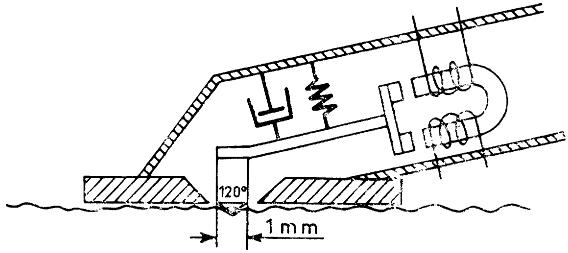

Fig. 7—Schematic drawing of the synthetic fingertip
This device described in the text is currently being tested to measure the surface softness

The apparatus has the advantage that, with appropriate setting of test conditions, especially elasticity and damping of the stylus, the signal obtained will be influenced in a variable manner by the mechanical properties of fibres and other projections in the surface of the sample. With the equipment described, it was found that the generated electric signal in itself (for instance, the RMS value) was insufficient to describe the surface softness otherwise than to give a very coarse indication—like soft, medium and rough.

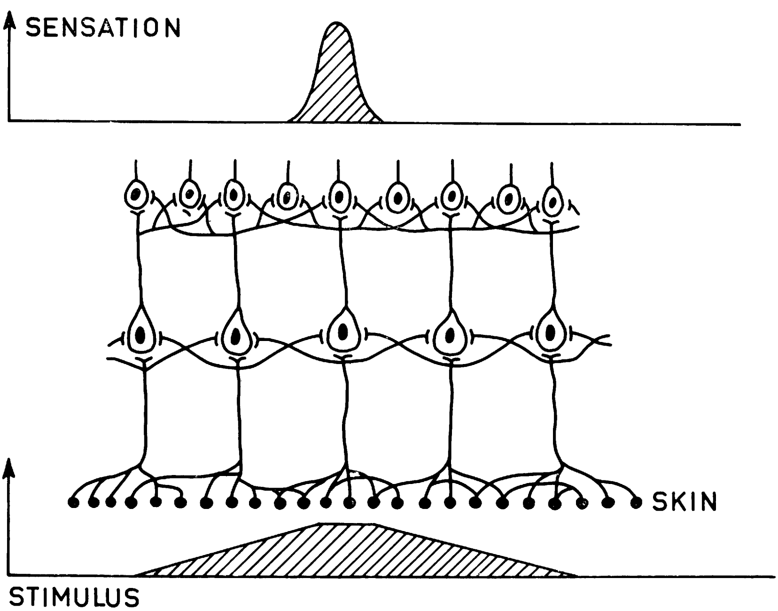

Fig. 8—A broad tactile stimulus is sharpened so that the perception is more like a peak

In the following, an approach is described that will account for and eliminate the discrepancy between the generated signal and the subjective evaluation.

If a vibrating plate is placed in contact with the human body (for instance, the arm), it can be observed that the sensation of vibration is felt to be allocated to a much smaller area than that of the plate (Fig. 8). This phenomenon is not limited to tactile perception.It is part of Mach's law of contrast (that is, for vision) and is involved in hearing. For the skin, the maximum of vibratory amplitude is always directly beneath the vibrator for all frequencies, whereas the place of maximum amplitude within the ear changes with frequency.This is what enables us to distinguish between tonal frequencies. It is obvious that this sharpening effect going from stimulus to sensation is important for the perception of softness and must be taken into account when relating subjective softness to the electrical signal from the transducer system.

The signal is treated as follows (Fig. 9). The raw signal from the cartridge, which is the derivative of the surface contour, is shown at the top. With the electronic circuit the highest peaks in the raw signal are picked out and amplified selectively—that is, the portion of the curve exceeding a limit voltage is amplified. The resolving power is varied by filtration.

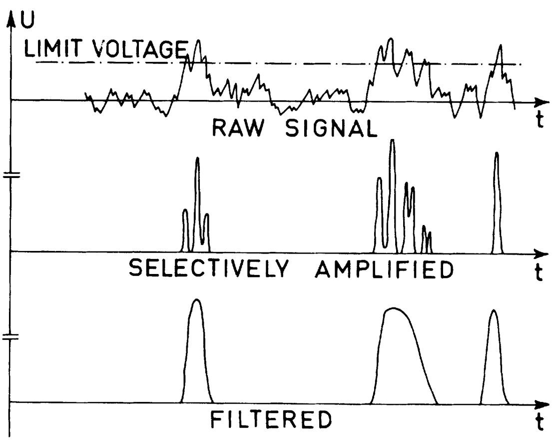

Fig. 9—Treatment of the transducer signal: selective amplification and filtration

Two characteristics of the final signal are believed to be of importance—the height of the peaks and the number of peaks per length of scan. The ratio of the height of the peaks to the number of peaks is plotted in Fig. 10 as a function of the subjective surface softness ratings. The resulting correlation is encouraging, but the method is still extremely sensitive to variation in test conditions. Furthermore, new variables are introduced into the electronic circuit in addition to those previously mentioned. At present, efforts are being made to increase the reproducibility of the system.

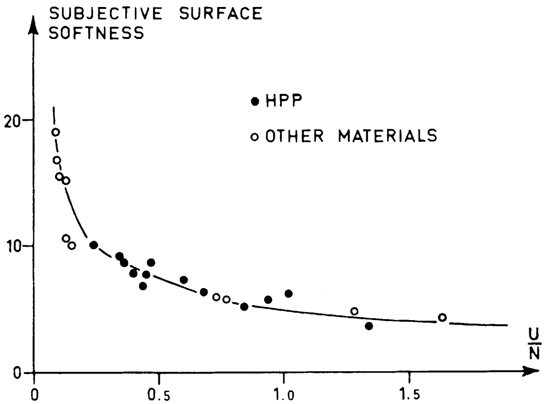

Fig. 10—The ratio of the height of the peaks in the final signal to the number of peaks per length of scan plotted as a function of the subjective surface softness ratings

A variety of materials are included such as tissue, non-woven, textiles, leather and ordinary paper

References

1. Wahren, D. and Nilsson, K., STFI, Series B 32
2. Brown, T. M., *Paper Mill & Wood Pulp News*, 10th June 1939, p. 19

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.