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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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RECENT DEVELOPMENTS IN CHEMICAL FINISHING 1/

by

S.A. Heap
Project Manager (Finishing)
International Institute for Cotton
United Kingdom

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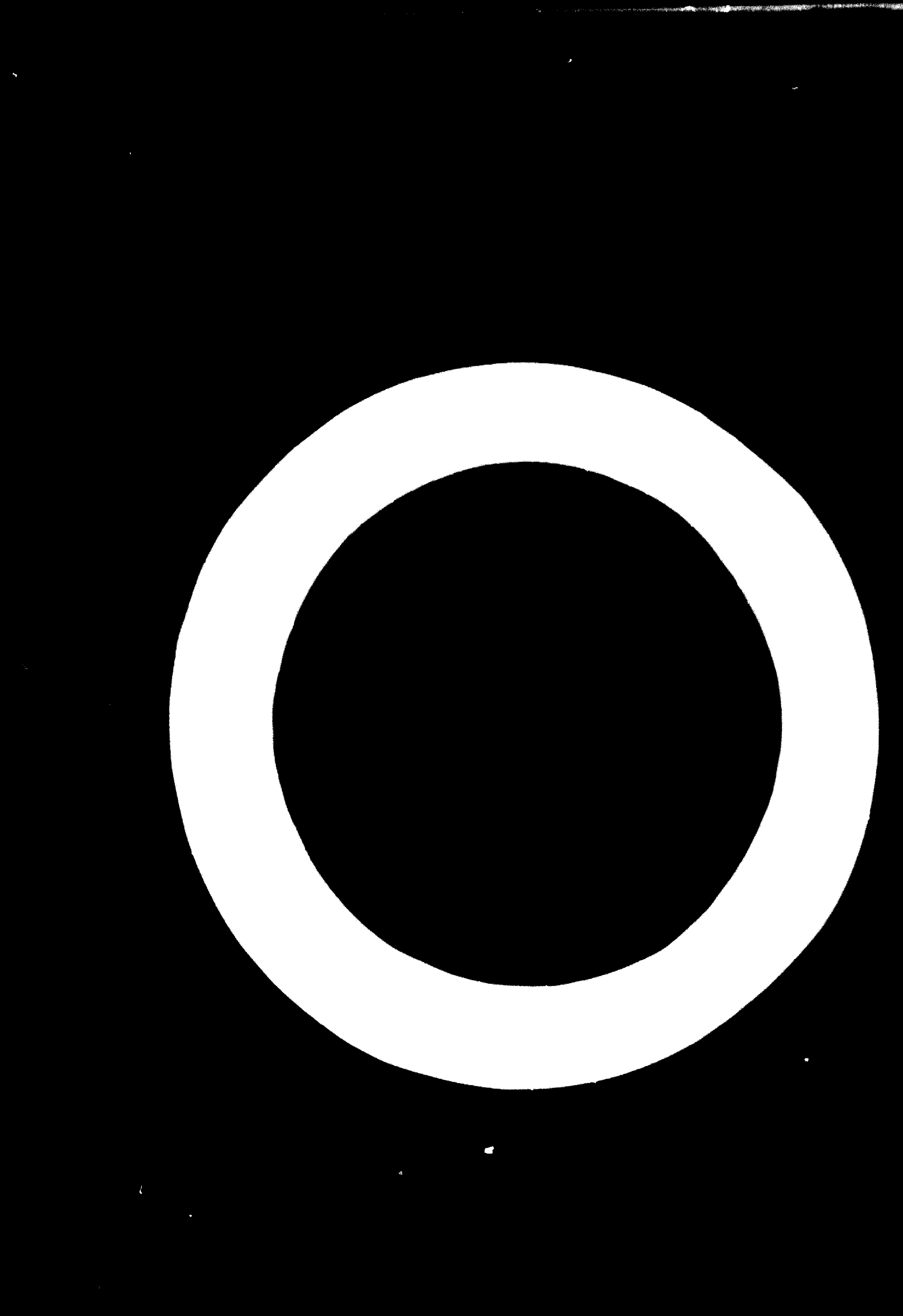

RECENT DEVELOPMENTS IN CHEMICAL FINISHING

I would like to start by attempting to put the importance of chemical finishing for cotton into some kind of perspective by looking at the end-use markets. When I say chemical finishing, I am referring to the finishing of cotton fabrics for easy-care properties. Of course there are other types of chemical finishing but they are a minority.

About half of the world's consumption of textile fibres is in the form of cotton, and cotton's three major end-uses are Apparel Fabrics (about 50%), Household Textiles (about 30%) and Industrial Textiles (about 20%). The absolute quantities of cotton going into all these markets are rising slowly year by year but if we consider the percentage share of the market, then cotton's portion is seen to be declining. This decline is greatest in the apparel fabrics market and it is this part of the market which shows the greatest growth potential and in which easy-care attributes are the most important.

Dr. Hans Koedam of the IIC Market Research Division gave a comprehensive survey of cotton markets and consumer opinions at the International Symposium on Cotton Research in Paris last year [1]. Three of the main conclusions from Dr. Koedam's paper were :

FIRSTLY there is a strong demand from the modern consumer for easy-care textile products.

SECONDLY the potential market for easy-care products embraces at least 60% of the Apparel and Household markets combined - we took some figures supplied by the Market Research Division for consumption of cotton by end-use in the UK and made estimates, item by item, of the percentage which is chemically finished for easy care. Excluding Industrial textiles, we came up with estimates of about 45% of total consumption or 70% of apparel fabrics.

Projected on a world-wide basis, the potential market for easy-care cotton products is estimated at 25 million bales, almost half the total world consumption.

THIRDLY, consumers have a strong natural preference for cotton products provided that they have the easy-care properties which are demanded.

On the basis of this kind of evidence, and more besides, the message from market research studies is clear. It is that the single most important technical problem for cotton, and at the same time cotton's greatest opportunity, is to match those properties of the synthetic fibre products which have stimulated this enormous consumer demand for easy-care garments.

Now, so far as we know, there is only one way of conferring adequate easy-care properties on cotton and that is by a chemical crosslinking process. For those who are not familiar with the techniques involved ... The chemical crosslinking agent together with a catalyst is applied from aqueous solution. The fabric is squeezed to ensure even pick-up and penetration and dried, then it is heated at about 150°C for a few minutes to complete the reaction. The treatment is quite simple and not too expensive - the whole operation can be carried out in a single continuous flow at speeds of up to 200 yards per minute.

By this means, there is no difficulty in obtaining easy-care properties which are equivalent to those of the competing synthetic fibre or blended products and in certain circumstances the easy-care properties can be better. For example, if a blended product is washed at a temperature much above 60°C, very drastic creasing is introduced which is extremely difficult to remove, whereas there is no such problem for all-cotton goods.

This property of cotton to withstand high washing temperatures would appear to be a distinct advantage over the competing blended products since it means that better cleaning can be achieved for the same easy-care performance. However, it does not seem to have had much effect in the USA where blends are now in a dominant position. The main reason for this state of affairs appears to be the one major disadvantage of easy-care finished cotton fabrics - that is the loss in durability which is caused by the crosslinking process.

Now I said that there is no difficulty in obtaining excellent easy-care properties on 100% cotton fabrics by crosslinking and this is true. The difficulty is that as the concentration of crosslinking agent in the fibre increases, so the strength of the fabric goes down. Because of this effect the finisher has to compromise : he has to use a lower amount of crosslinking agent so as to keep an adequate durability of the fabric, but in doing so, he has to content himself with less-than-optimum easy-care properties. This so-called "balance of properties" is very probably the key to the sucess or failure of cotton as a competitor in the easy-care market. If we cannot find the key which allows us to maintain a high level of durability together with a high level of easy care, then the easy-care market will become dominated by synthetic fibres. And as I said before, the easy-care market could account for half of cotton's production.

There has been a great deal of research in the past to find a way out of this problem and most of this has concentrated on attempts to change the chemistry of the crosslinking reaction. The result of the last 20 years' work is that we now have an excellent range of crosslinking agents available which excel in such properties as resistance to laundering and bleaching and minimum effect on whiteness or on shade of dyestuffs, but the central problem remains unsolved - however much we changed the size, shape or chemistry of the crosslinking agent, we still obtained essentially the same inverse relationship between easy-care properties and durability.

More recently a slightly new approach has been tried in which the processing conditions are varied so as to ensure that the crosslinking reaction takes place not at very high temperatures when the fibre is bone dry, but at low temperatures in the presence of defined amounts of water or other swelling agents, so the cotton is, so to speak, fixed in a more natural configuration. The result is a significant improvement in the balance of properties so that one obtains a better easy-care performance for a given durability.

Several processes which work on this principle have been developed, the most recent one at the Shirley Institute under IIC sponsorship.

This new process consists essentially of replacing the conventional high temperature baking step with a passage through the vapours of a boiling organic solvent. The use of boiling vapours ensures extremely precise control of temperature, a very efficient transfer of heat by condensation, and also the presence of some moisture during the cure. As a result we can obtain genuine improvements in the balance of properties together with a much closer degree of process control, but even so we still have our inverse relationship between easy-care properties and durability so that the performance of these fabrics will still be a compromise.

So it seemed to us when we were setting up a basic research programme for IIC that a new approach was needed. Somehow we had to find how to improve the response of the fibre to crosslinking treatments. We felt that the answer must lie in the fine structure of the cotton fibre and how the fine structure was influenced by crosslinking. Therefore we set out to obtain a better understanding of three basic and interrelated questions :

FIRST : How do the mechanical properties depend upon the fine structure ?

SECOND : By what mechanism does the crosslinking reaction affect the mechanical properties ?

THIRD : Can the existing structure be changed, by chemical or physical means, so as to produce a fibre with better mechanical properties and a more favourable response to crosslinking ?

1. How do the mechanical properties depend on fine structure ? - As you know the cotton fibre is constructed from fibrils. There are about 15,000 of these fibrils in a fibre of average maturity and each fibril is composed of about 400 smaller elementary fibrils, making about 6 million in all.

The fibrils spiral around the wall at an angle of about 22° with periodic reversals and the general aspect of the fibre is of a collapsed, twisted tube.

Now the elementary fibrils are almost perfectly crystalline and therefore we must consider them to be very strong. (Even after very severe mechanical beating or chemical swelling treatments, they seem to retain their individual identity). However the fibre, as we receive it, is not strong and therefore we must suspect that during stress a good deal of slippage at fibrillar surfaces takes place and we can postulate that the strength of the fibre is very intimately connected with the precise pattern of slippage and stress distribution which develops under load. Obviously the better are the lateral contacts between fibrils, the higher is the resistance to slippage and the stronger is the fibre because the load will be transferred from fibril to fibril throughout the fibre. Also we may suspect that if slippage is more likely to occur in one particular area of the fibre, a crack may develop which could lead to premature failure. In other words, the strength of the fibre is probably critically dependent upon the uniformity of contacts between fibrils throughout the whole fibre mass.

Unfortunately it has been found that no such uniformity exists, in fact quite the opposite. Apparently the degree of packing of the fibrils varies tremendously according to the specific part of the fibre under consideration, and it seems as though this might be directly related to the way in which the fibre has initially collapsed during its first drying out in the cotton field [2]. The amount of non-uniformity produced by this collapse is probably a rather complex function of the maturity, the fineness and possibly also the distribution of reversals. The outward indicator of this mixed up state of affairs is the characteristic bean-shaped cross-section and the severity of convolution in the fibre.

If we are to increase the strength of cotton fibres I believe that we must try to eliminate these large differences in the degree of packing of the fibrils and to do this probably implies the production of cottons which do not collapse so catastrophically during first drying.

2. The second area in which we said there was a lack of knowledge was the mechanism by which crosslinking affects the mechanical strength.

Well, we really have no more concrete evidence on this subject than we had at the start of our researches but as a result of the discoveries in fine structure we can at least form a more intelligent hypothesis.

What happens when we apply an easy-care finish is that we make chemical reactions at the surfaces of the fibrils. Now these chemicals are capable of reacting in at least two places and so in theory they can make a cross-link between two adjacent fibrils. The effect of this is a stronger bond between fibrils which we have said before should give an increase in strength. Well, so it may at that particular point. But the crosslinking molecule has only a limited size and therefore there will be many places where the space between fibrils is just too great for crosslinking to occur and hence these places will be left weaker than those which have been crosslinked. Now this would not be so bad if such places were uniformly distributed throughout the fibre but unfortunately they are not ; they are concentrated in very specific areas of the fibre. This means that we have actually accentuated the differences in mechanical properties between different areas in the fibre - whereas before a certain amount of slippage could occur in the strong areas to help spread the load around the fibre a little, in the crosslinked fibre what we have probably done is to effectively isolate a relatively small fraction of the secondary wall and force it to bear all the load.

Therefore it is little wonder that we get drastic losses in strength and durability as we increase the level of crosslinking.

3. The third area for research was "Can the existing structure be changed so as to produce a fibre with better mechanical properties and a more favourable response to crosslinking ?"

If the reasoning already presented is correct then the poor mechanical properties of the fibre and the reduction of strength after crosslinking are both results of the same phenomenon, that is the difference in the packing density of fibrils in different parts of the fibre. Therefore if we can re-arrange the fibrils so that the degree of packing is more or less the same in all areas, we should hope to be able to cure both illnesses with the same pill.

The most immediately obvious way to achieve a repacking of the structure is to attempt to swell the fibre back to a cylindrical form and then recrystallise it in a more uniform way than occurred in the original drying after boll-opening.

The most common swelling agent which might be able to do this job is caustic soda as used in the commercial mercerising process.

Now it has been known for some time that strength increase can be obtained by mercerising treatments. For example, Rebenfeld published in 1958 [3] some results obtained by holding fibres at constant tension whilst subjecting them to a mercerising treatment in caustic soda.

He tested twelve different varieties and found that the results were highly dependent upon the variety chosen - strength improvements ranged from none at all for KARNAK to about 70% for CONGO.

Mercerising at Constant Tension [2]

Variety	Strength % gain	Elongation % loss
Karnak	0.7	34.2
Lengupa	1.5	40.3
Pima - S 1	5.8	45.5
Watson Mebane	17.1	40.6
Experimental Strain	27.2	44.1
Acala 442	29.9	29.1
Supima	30.2	21.5
Triple Hybrid	35.0	5.3
Sea Island	38.2	34.1
Coastland	52.0	26.4
Deltapine 15	52.8	30.3
Congo	73.6	38.2

Rebenfeld said that the results were not correlated with any known property of these cottons.

In this work no attempt had been made to optimise the treatment for each variety but the following year a publication by Radhakrishnan [4] and co-workers demonstrated that even when the fibres were allowed to shrink in mercerising caustic solution and then were restretched, to the maximum possible degree, to develop the maximum possible strength, then the results obtained were still very dependent upon the fibre variety.

Although they gave results for only a few varieties, the maximum obtainable improvement in strength varied from about 50% to over 200% of the original. Therefore we were quite sure that some improvement in strength could be obtained by swelling treatments, but it had not been demonstrated convincingly - so far as we were aware - whether one could significantly affect the relationship between loss of tensile strength and degree of crosslinking by a mercerising pretreatment.

In an IIC sponsored research project in Holland the TNO Fibre Research Institute is studying the effects of such swelling treatments before applying crosslinking agents.

They have shown that if you take a bundle of fibres and swell them thoroughly in mercerising sodium hydroxide solution, then restretch them to their original dimensions, rinse out the soda whilst maintaining these dimensions and then dry - the fibres obtained have a tensile strength of anything up to 100% greater than the original with little or no loss in elongation at break.

If we compare the tensile strength of the modified cotton before crosslinking with that of other common textile fibres, the nearest rival is the high tenacity polyester.

Stereoscan electron micrographs of our "High Tenacity Cotton" show that the familiar flattened, rough, twisted ribbon has been changed into a smooth, solid, cylindrical rod. The change in the internal appearance is no less dramatic ; there is a much greater degree of coherence and, perhaps more important, a much better uniformity of coherence through out the body of the fibre.

I think that our Dutch co-operators have demonstrated that there are quite significant improvements to be made in the mechanical properties of cotton and that, in principle, the problem of producing an easy-care cotton with high strength has probably been solved.

I say "in principle" because of course we are nowhere near a practical process yet These results have been obtained on fibres and there are formidable difficulties to be overcome if we wish to reproduce these results in yarn or fabric. However, we are proceeding with a development programme and no doubt we shall eventually get there.

We have been very encouraged recently by a new process which has been announced by J. and P. Coats Ltd.. Coats are the world's largest manufacturers of sewing thread and they have perfected a new method of mercerising yarn with uses liquefied ammonia instead of the conventional caustic soda solution.

They have built a very impressive pilot plant of about 400 spindles which can continuously mercerise yarn at about 150 metres per minute. The process is commercially attractive because it eliminates the need for a special rewinding process after mercerising which is a major cost saving. Technically it is even more attractive because the strength of sewing thread can be increased by 40% quite easily and for two-fold yarns improvements of up to 80% are normal.

Now these developments with liquid ammonia seem to be very important to us for cotton for two reasons : Firstly, it is potentially cheaper and simpler to use than caustic soda. Although the soda itself is cheap, it is rather slow to penetrate and is held very tenaciously by cotton. Therefore it requires an extensive washing and neutralisation process and this is expensive in time, water, energy, and machinery space. In addition we have a caustic effluent to dispose of which must be treated before it can be discharged. Ammonia on the other hand has a rapid reaction, is very quick and easy to remove from the fabric, and can be recovered for re-use.

Secondly, ammonia has a lower swelling power than caustic soda. At first this may seem to be a disadvantage but in fact the result is to achieve a more uniform penetration throughout the yarn or fabric than is possible with caustic soda. The reason for this is that as soon as fabric contacts the soda, the outermost fibres swell to such an extent that they become jammed together and thus prevent the liquor from penetrating to the interior. Therefore the fibres are usually only fully mercerised in those parts which happened to lie on the outer surface of the fabric.

We suspect that although liquid ammonia may not be quite as good as caustic soda when treating single fibres, for yarns and fabrics it may produce a more uniform product - and uniformity means strength.

Therefore it seems to us that we have a very clear indication of the path forward. We must pay a very close regard to the structure of the fibre which we are using and it is important that we can get fibres of the maximum structural uniformity. These swelling treatments are very difficult to carry out as efficiently as we would like to under commercial conditions because of the limitations on swelling which are imposed by yarn and fabric structure. If breeders and growers could meet us half-way by providing a fibre which is easier to mercerise - maybe one which has collapsed very uniformly, or which has collapsed very little, or even maybe not collapsed at all - then we will stand a much better chance of success in making uniform treatments even in a fairly tightly constructed fabric.

I would like to conclude with a last word to the breeders of cotton from the finishers. We think that the structural non-uniformity of cotton could be our biggest enemy in the easy-care battle against synthetic fibres because it reduces strength and prevents us from applying the best easy-care finishes that we have.

We think that structural non-uniformity could be tied in with the severity of collapse which the fibre undergoes on first drying from the newly opened boll, and that this in turn could be related to the relative dimensions of cell wall and lumen.

We cannot yet tell you what the dimensions of the perfect cotton fibre should be or how to set about breeding it and therefore we appreciate that by offering you a concept rather than a fibre specification we are probably offering you a big headache.

However, we are sure that we can do quite a lot to improve the properties of our fibre to make it more competitive in the easy-care market, and you can make our job so much easier if you can find some way to give us a fibre which is structurally more uniform when it reaches us.

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