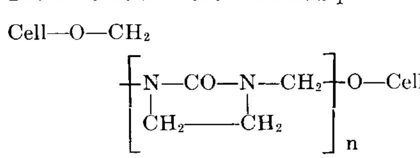
size of the cross-links, their location within the fiber, and the extent of cross-linking should be influential in controlling the properties of the treated fabric. Knowledge relating to each of these factors would be highly instructive and useful, but their analytical determination poses very difficult problems.

Size of the Cross-Link

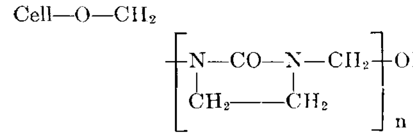
Wrinkle-proofed cotton invariably shows a loss in strength. A small part of this loss can usually be attributed to hydrolysis of the cellulose resulting from the acid nature of the catalyst. Much of the loss, however, results from the presence of cross-links between the structural elements: any factor which adversely affects the distribution of stress must also reduce the tension at break. Very short cross-links would be very effective in reducing slippage of structural components past each other, but they would also cause a build-up of areas of high stress concentration, with consequent failure at lower loads. Very long cross-links ought to reduce strength to a much lesser extent, but their effectiveness in improving crease recovery by reducing slippage should be less, depending on their length. Suggestions have been made that agents be used that will form elastic or rubbery cross-links. Such agents would allow relative motion of the structural elements, giving a favorable distribution of stress; when the applied stress is removed, the elastic links would restore the fiber to its original configuration.

Some effort has been made to determine the degree of polymerization (DP) of the intermolecular cross-link formed by certain monomers, e.g., dimethylol ethylene urea, which is capable of forming only linear polymers since it has but two functional groups. This molecule reacts with the cellulose molecule to give the intermolecular cross-linked product or the side chain product:

Intermolecular cross-linked product



Side chain product



Nitrogen analysis will determine the number of ethylene urea residues on the cured fabric. The number of bound formaldehyde groups can be determined after their release by acid hydrolysis. The molar ratio of formaldehyde to ethylene urea residues, which varies with n, can be used to determine DP. The distribution of product between the intermolecular cross-linked compound and the side chain compound is not known, and is unimportant for calculation of DP so long as both compounds are stable under reaction conditions. It has been reported, however, that the terminal *N*-methylol group of the side chain compound is unstable under normal curing conditions:

$$>N—CH_2OH \rightarrow >NH + CH_2O$$

It is evident in this case that the ratio of formaldehyde to ethylene urea residues for the cross-linked product would vary from 2, for $n = 1$, to 1 for large n, whereas the ratio for the side chain compound would always be one. Under these circumstances an accurate estimate of DP is impossible. One estimate puts the cross-link at between one and two ethylene urea residues long, assuming the entire reaction product is the intermolecularly linked compound (*1*). In other work, where the opinion was expressed that free $>NCH_2OH$ groups can withstand curing conditions, the estimate of DP ranges from 2 to 5 ethylene urea residues (*5*). It is evident that the accuracy of the estimate of DP varies with the extent to which the terminal $>NCH_2OH$ groups break down, this in turn depending on reaction conditions.

Location of the Cross-Links

The location of the cross-links in the fiber is important with respect to its influence on the mechanical properties of the finished fabric. It