# Functions and Care of Paper Machine Rubber Rolls

## —A REVIEW

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*Important role of rubber covered rolls in the present day concept and design of paper machine presses has been indicated. Chemistry of natural and synthetic rubbers has been outlined and its bearing on the properties of the roll discussed. The salient points of the rubber technology in the manufacture of these rolls have been mentioned. The theory of wet pressing as far as the rubber rolls are concerned has been reviewed. Crushing of paper in the press due to rubber roll has been indicated. Acceleration in the rubber due to noncompressibility of rubber and its deleterious effects have been mentioned. Damage due to heat build-up in the rubber covers, Hysteresis variables in prolonging the life of the rubber rolls, different kinds of troubles with rubber rolls and their possible remedies and the care required in getting the best out of rubber rolls have been discussed.*

**INTRODUCTION**

Paper machine rubber rolls have of late attracted greater attention and closer study. Increasing speeds, larger deckles, bigger roll diameters, greater nip pressures, and consequently rising roll temperatures have all gone in to underline the increasing severity the rubber rolls will be called upon to stand upto. The rubber technologist has tried to keep pace with the rapidly advancing strides made by the machine designers. But the optimal benefit can best be achieved only with matching awareness on the part of the operational and maintenance people.

This review aims at focussing attention at some of the significant parameters in this regard.

A very brief outline of the rubber chemistry and technology here will be helpful in providing a back-drop for such an understanding.

**CHEMISTRY & TECHNOLOGY**

Rubber is obtained from the sap of a number of trees belonging to the APOCYNACEAE, MORASEA and EUPHORBIACEA families. Incision of the bark yields LATEX, the milky fluid which is then polymerised to give crude rubber. The latter consists essentially of CAOUTCHOUC, the hydrocarbon constituent of rubber, which has an empirical formula of $(C_5H_8)n$, most likely in the form.

$$— CH_2 - CH = C(CH_3)\ CH_2 —$$

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Polymerisation (isoprene) leads to formation of a macro-molecular structure of long open, or possibly closed, chains, built up from isoprene units and containing one double bond for every five C atoms; The exact atomic structure of rubber, however, still remains inconclusive.

These chains are comparatively readily separated by solvents. On vulcanisation sulphur enters into combination $(C_5H_8S)$ at each double bond available and not used for link formation in the macromolecule. It is this change in the molecular pattern which imparts rigidity to the compound, makes it more resistant to solvents and modifies its physical properties in general.

CAOUTCHOUC is remarkable for its great elasticity. But with rise of temperature it gradually loses this valuable property, and on being cooled it becomes hard. To minimise these defects the great bulk of rubber used industrially is vulcanised, which also renders it stronger, more elastic and practically insoluble in the common solvents.

Vulcanisation is effected by heating with steam under pressure, in air or $CO_2$ after mixing the dry material with sulphur and other ingredients, such as fillers, accelerators and anti-oxidants and heating to 120, to 160 °C for 8 to 100 hours depending upon the size, weight and hardness of the roll. Soft rubber is produced when sulphur is kept at 3 to 10% and hard with raising sulphur content upto 35%.

Accelerators serve to speed up the process of vulcanisation primarily. But these also improve the quality of the product, giving increased strength and greater resistance to abrasion. Both inorganic and organic compounds are used for this purpose. To the former class having compounds like metalic oxides (Lead or Magnesium) and to the latter the amines.

Fillers are used to modify the stiffness, strength and other properties of the finished product. Barytes, ground slate, carbon black, zinc oxide, magnesium carbonate are some of the fillers commonly used for different purposes.

Anti-oxidants are meant to delay oxidation and ageing of the rubber in light and air, which result in hardening, flex-cracking and loss of tensile strength. There is a large number of compounds which are used for this purpose, such as amines, aminophenols, aldehyde amines, amino ketones and their condensation products. These are used in quantities varying between 0.5 to 2.0% depending upon the result desired.

Synthetic rubbers are produced by polymerising hydrocarbons containing conjugated double bonds. The rubber-like product formed is then vulcanised and worked up in the usual way. The most commonly used synthetic rubbers are: BUTADIENS, $CH_2$:CH.CH:$CH_2$, and its derivatives, and NEOPRENE, — $CH_2$.CCL = CH.$CH_2$. $CH_2$.C Cl = CH.$CH_2$ — and its derivatives. Some of the properties of natural and important synthetic rubbers are given below:

| | Natural rubber | Styrene-Butadiene copolymer GR-S | Butene-Diene Copoly mer | Neoprene Polychloro prene. |
|---|---|---|---|---|
| Density | 0.92 | 0.94 | 0.915 | 1.23 |
| Sp. Heat, Cal/g. | 0.452 | 0.454 | 0.464 | — |
| **Gum stocks:** | | | | |
| Tensile strg. psi | 3100 | 300 | 2000 | 2800 |
| Elongation % | 775 | 380 | 800 | 600 |
| **Black loaded stocks** | | | | |
| Tensile strg. psi | 3900 | 3000 | 2200 | 3600 |
| Elongation, % | 780 | 650 | 600 | 350 |
| Stress 300%, psi | 1400 | 1200 | 8000 | 200 |
| **Swelling: % by volm, in** | | | | |
| Kerosene at 25 °C | 200 | 100 | 300 | 60 |
| Benzene at -do- | 200 | 200 | 300 | 150 |
| Acetone at -do- | 25 | 30 | 30 | 20 |
| Mineral oil at 75 °C | 120 | 150 | 130 | 10 |
| Resilience, % | 90 | 75 | 50 | 75 |
| Tear resistance, psi | 1640 | 550 | 1000 | 1100 |
| Crepe, 70 °C | 26 | 14.6 | — | 62 |

The values given above are the comonly representative for each type. It is to be appreciated that considerable variation may occur or can be made to occur since properties of a rubber compound can be varied greatly by choice of fillers, accelerators, etc. as well as conditions of cure and numerous other factors. It is here, therefore, that the rubber technologist's experience and knowledge of the requirements of a paper machine rubber roll in a specific position and functional conditions plays an immensely important role. Especially in our country where the rubber technologist has taken up supplying the neds of the paper industry only recently, largest cooperation between these concerned will go a long way in proper design of rugger covers.

The other points that concern the rubber technologist are: he has, in the first place, to make sure of the metal body of the roll being strong, true and reliable. Secondly, the surface of the body must be absolutely free of dirt, scale, rust and any other foreign matter. This he does by sand-blasting. This is evidently a very major step inasmuch as it has tremendous bearing on the bonding of the rubber cover onto the roll. He then chose the correct bonding agent for aplication on the roll surface which will provide the maximum bonding between the rubber and the roll body.

Rubber is applied on the body in the form of uniform sheets of about 1.5 mm thickness. These sheets are produced in the calender from the rubber mass which has been compounded with numerous chemicals, mixed in the mixing mill. At this stage care has to be taken to prevent scorching as wel as inclusion of any foreign material.

During the application of the rubber sheet considerable skill is required to accomplish a perfect job. The sheets must be perfectly and no air should get in to form blisters. Cotton tape under pressure is then wrapped on and the roll is moved into autoclaves of suitable size for vulcanisation. After vulcanisation, the roll is cooled and then finished on the grinding machine to correct size.

**THEORY OF WET PRESSING**

It is not the purpose of this paper to review in detail the theory of wet pressing. The intention is to refer mainly to the present-day thinking on the subject that has relevance to the functioning of the rubber rols.

Rapid progress in modern paper technology, resulting in really fast and huge paper mechines with all the promise to do still better, owes quite a great deal to th better appreciation of what is happening in the nip of a wet press. It started with **Nissan** who in 1954 set out his famous theory explaining the role of wet press in the removal of water. But it was Walstrom who in 1960 presented the result of his extensive and detailed study which is the prerunner of the present concept of wet pressing. Subsequently many others, prominently Cosgrave, Howe, Wrist, Schiel, Chetwin, Nilsson and others have contributed to our present-day knowledge on the subject.

Although initially the study was aimed at explaining the working of the suction presses, and conclusions were related thereto, it is now accepted that the same fundamentals of wet pressing are common to all types of press. The plain and the suction presses are treated as special cases rather than as different basic types. The major objective of the press remains to be the removal of water from the paper web. One or more other elements are also usually present in the nip such as wet felts, plastic wires covers on the rolls, perforations etc. which might be considered as compressible for our discussion here although these are not considered so as well be seen later. The rubber cover of the plain press may be thought of as a compressible, but non-porous structure. The cover of the suction roll is a non-fibrous structure which is compressible, has transverse permeability but no lateral permeability. The grooved cover gives a very high permeability through the nip but no transverse permeability. In all cases some water leaves the press nip in the web and the other structures and in addition, ahead of the nip, through the face of the rolls and beyond the nip on the surface of one of the rolls.

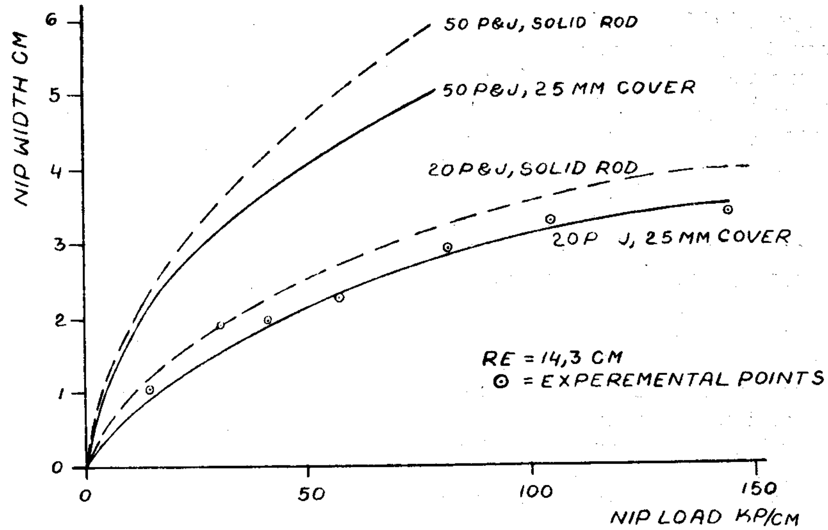


**Fig. 1. Nip width of rubber covered rolls.**

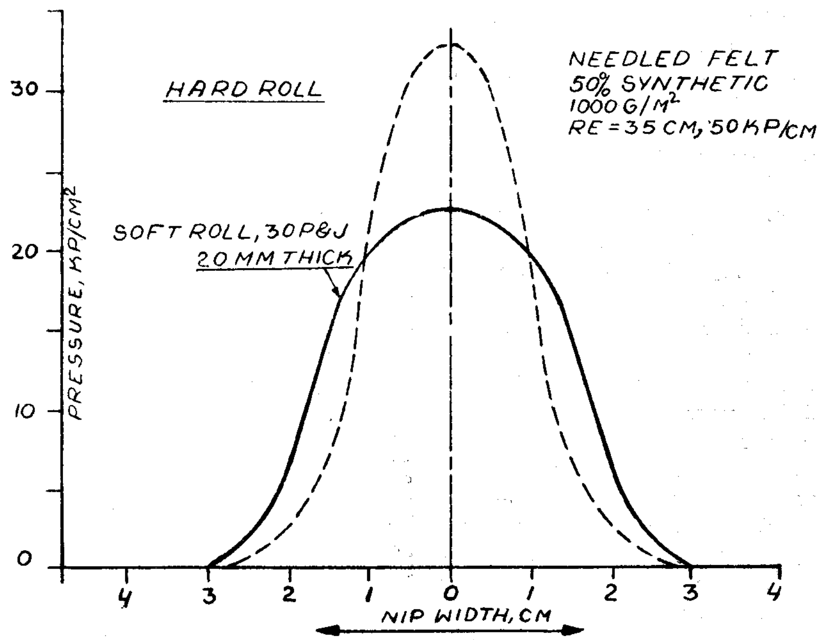


**Fig. 2. Static Pressure distribution in a press nip.**

The lower efficiency of the plain press is due to the fact that while in other presses removal of squeezed out water being fast the flow of the water is transverse, that is, perpendicular to the run of the paper, whereas in the case of plain press there is lateral flow also, that is, along the felt before the nip. This causes the felt to enter the press nip with a much higher hydraulic load. Consequently the wetter felt is not able to remove as much water from the web as the other presses can. For this reason the compressibility of the nip of a plain press is by far more critical. In fact all the developments on the plain press, such as the suction press, the grooved press or Venta-nip press, fabric press and the H₁-I press, have been the result of efforts aimed at reducing this criticality or inefficiency of the plain press. And the fast progress in better press designs, including the new design of wet felts with built-in mono-filament fabric has its origin in the Nissan-Wehlstrom theory.

## THE RUBBER ROLL AND THE THEORY

Summarizing the second International symposium on Water Removal at the Presses and

Dryers, held in Canada in October 1968, Wrist said, "In summary then, a transversal flow press behaves as follows: On the ingoing nip paper and felt are compressed with water flowing from the web through the felt into receiving channels — fabric, grooves or suction holes. On the outgoing side the paper and felt both expand, and in so doing redistribute water level held close to their contact faces. In this phase there is usually a flow from felt to paper; hence it is called the rewetting phase. This transfer has been clearly shown to be an interface-controlled phenomenon, rather than a function of the volume properties of paper or felt and has been shown to depend on the relative fineness of the pore structure of felt and paper and on the recoverability or springiness of the two surfaces. Thus the maximum possible dryness for a given press loading depends on the paper compressibility and the softness of the nip. The extent to which this level is achieved at the centre of the nip is controlled by the paper permeability and the time factor which in turn is determined by machine speed, roll diameter and nip softness."

This represents our present-day concept of the pressing action. Significant, almost spectacular, improvement in the press performance has been achieved by working along this concept which has given birth to different designs and combinations as we know today.

From Wrist's very appropriate summary, the important role of the nip and, therefore, of the rubber roll is evidence. The nip width is the function of the rubber cover hardness and the thickness. The linear nip pressure depends upon the press load and the nip width. It is known that the nip width and the pressure in the nip will change proportionately to the square root of the nip load. **Fig. 1** gives an idea of this graphically.

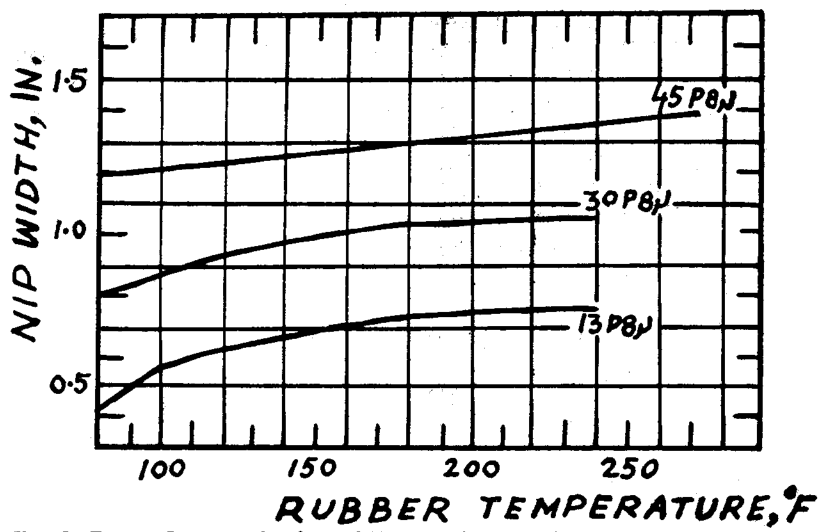

**Fig. 3. Dependence of nip width on temperature.**

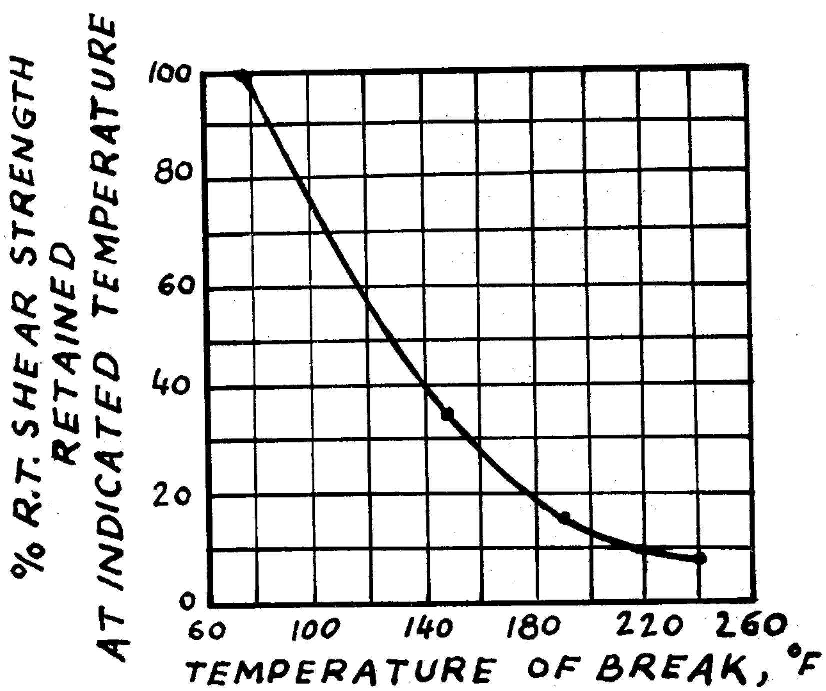

**Fig. 4. Shear strength relation with temperature of break.**

**Fig. 2** gives an idea of the change in nip width with roll hardness.

As shown by Schiel, Hertz equation can be used with necessary modification for theoretical evaluation of nip width for two rolls in contact. But in the case of felted rolls this becomes difficult and the derivation has to be done experimentally. It has also to be appreciated that the influence of nip width is difficult to assess in isolation as the speed, that is the time factor, the felt and the quality of the product have all a bearing on the performance of the press. The ideal situation in the press would be steadily increasing pressure through the nip, being maximum at the centre with a fairly sharp decrease at the end of the nip. But this condition is difficult to fulfil with rotating rolls as would be discussed presently. All that can be done to improve the pressing conditions at a given nip load is to alter roll diameter, felt compressibility and the rubber cover elasticity and thickness. Bigger roll diameter, softer cover, thicker cover, and more compressible felt will all produce broader nip and therefore, lower specific load. Reversing these conditions will give sharper nip and consequently higher specific load. The optimum would be the maximum dryness obtained from the press. And, apart from the time factor and the quality of the product, Schiel has shown that this optimum condition is only a function of effective radius and nip compressibility. A change in speed alters pressing time at constant pressure. For a given press the slope of the optimum condition curve is proportional to speed. Establishing the optimal nip condition for every paper machine would mean worthwhile production increase and savings in press clothing and steam as well.

**CRUSHING**

Schiel points out that in optimizing the press nip geometry it must be borne in mind that the press nip must be kept sufficiently soft to avoid crushing under the most unfavourable operating conditions. These conditions usually exist when thick, low-freeness sheets are produced at high headbox consistencies and at high production rates. For determining critical crushing conditions, a crush causing power must be defined. He identifies the maximum horizontal pressure gradient in the nip as the most important cause. The nip conditions have to take into account all the factors, like pressing time, felt condition, rate of drainage, and nip pressure, and cannot possibly consider the role of the rubber roll in isolation. This is true for all types of crushing, be it incipient, wrinkles, fissures or complete crushing void in the web.

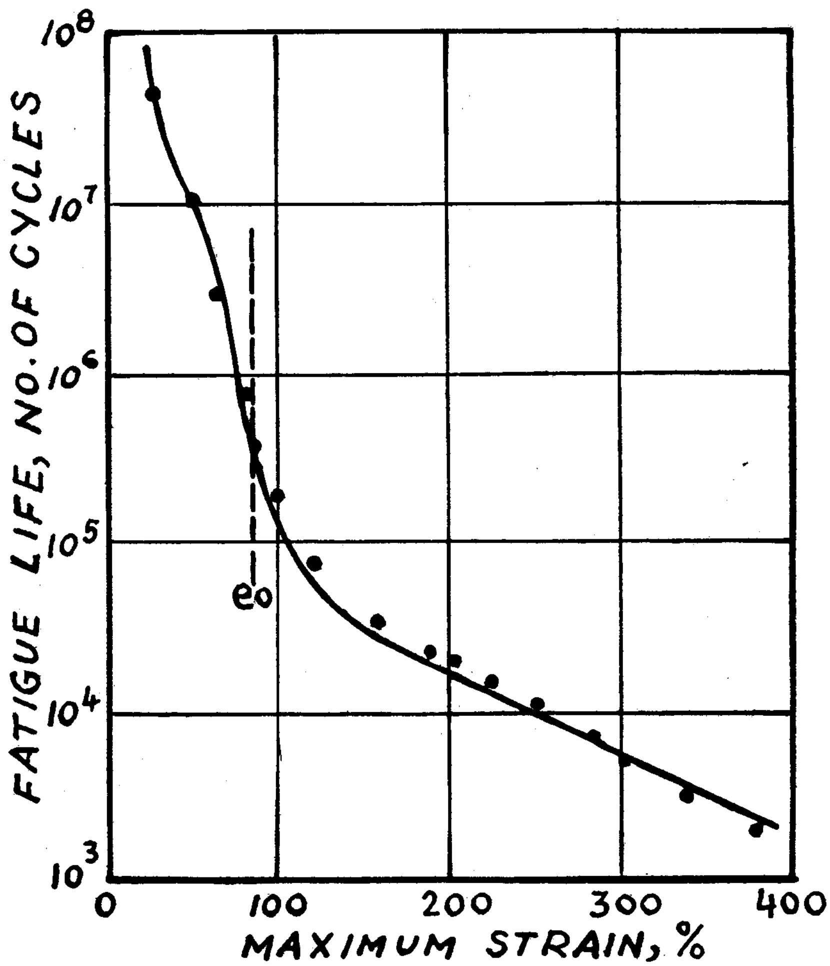


**Fig. 5. Fatigue results on a natural rubber gum vulcanization.**

**PULP CHARACTERISTICS**

It is essential to take pulp characteristics in consideration in any study of press conditions. Nilsson and Larsson suggest the two very relevant characteristics of pulp as the static compressibility of the pulp and the flow resistance of its fibre bed in compressed state. They show that the hydraulic pressure created by the flow of water between the fibres in the fibre bed does not account for the whole dynamic pressure in the nip. Other factors of relative importance are indicated to be inertia, the flow of water from within single fibres, the viscose behaviour of cellulose, and the infiltration of fibres in the surface of the felt.

**EFFECT OF RUBBER COVERING IN THE WET PRESS NIP**

The thickness of the rubber cover of a roll, and its hardness determine the width of press nip. One of rubber's disadvantages is that it is incompressible, being elastic. For th e same hardness, the elasticity can range widely. The amount of its displacement in a wet press without felt depends on its hardness and its thickness, as well as on the line pressure in the nip and the speed of the machine. Because of the stretching property, the rubber layer shows acceleration. Hurard describes its behaviour like that of a very viscose liquid and assumes its displacement ( constant) as given by the product of the average surface area and the speed. Based on actual measurements he gives this acceleration a value of 8.6%.

A felt cuts down this acceleration to 50 to 75% depending upon the kind of the felt. Thus the felt speed is shown to lie between the nominal speed of the bottom roll and that of the top roll.

This concept of acceleration in rubber covering is utilised to explain the following:

1. Damage and rapid ageing of the rubber covering. This results from the build-up of rubber before and in the nip that produces an increasing, then decreasing acceleration in the outer shell of the rubber layer. If the rubber is not fully vulcanised, permanent distortion occurs when the elasticity limit is lower than the stretching in the nip. If the elasticity limit falls with time, the rubber ages rapidly and crazing of the rubber surface can be observed. These effects can occur locally as well as throughout the covering, independently of whether or not the rubber's hardness and elasticity remain constant. A mistake in the roll crowning can also add to the localised crazing of the rubber covering.

2. Felt wear on the side running against the rubber roll can mainly be accounted for its being stretched and bared because of the acceleration of rubber.

3. Crushing is also to some extent due to this rubber acceleration and is inter-related to felt life.

4. Felt life depends upon how long the felt is able to allow for the acceleration of the rubber. As long as the felt remains supple it allows for the rubber movement and there is no trouble. But if the felt becomes stiff, even when not plugged, it will lead to crushing.

## SHRINK FABRIC PRESS

The shrink fabric press has advantage over the plain press only if increased linear pressure without risk of crushing can be attained. Only then lower wet moisture content would be achieved. Both rubber hardness and cover thickness are important in determining the shrink fabric life. slight build-up of the rubber just in front of the nip (invisible to the naked eye) causes acceleration of the rubber after the nip, which works the fabric forward, particularly on the crown of the roll. The softer the rubber, the greater the build-up and consequently the greater stretching of the plastic filaments, some times even to breaking point. According to Meijer, this is minimised by harder rubber (10-15 P & J) and a thinner cover (10 mm or less). A shrink fabric life on a suitable poll could be expected to be 3 to 4 months on a 200 or 300 M/min machine; 8 months on a 60 M/min board machine.

Rubber rolls are said not to face any such problems in the case of Hi-I and Venta-Nip/Presses.

## HEAT BUILD-UP IN RUBBER COVERED ROLLS

McNamee's study of the dynamic forces that operate in a press nip and how these forces effect rubber roll covers makes a useful contribution in the understanding of the functioning of the rubber rolls.

Rubber covered roll does its work as the resilient covering passes through the nip region or pressure area formed by contact with another surface, usually harder. Rubber being non-compressible, under load the cover displace laterally. This movement of the rubber each time a unit area sets up a cyclic motion in the rubber corresponding to the frequency of rotation of the roll. The aplitude of this motion has been shown to be a function of roll loading, dynamic modulus of the covering, rubber thickness and roll diameter.

The stress-strain behaviour of rubber — like (elastomeric) composition is described as Visco-elastic. This is said to result from the manner in which the long chain molecules undergo strain and recovery. Instead of acting in a truly elastic manner, these viscous exhibit some of the viscous response of liquids, which makes their properties extremely time (rate) and temperature dependent.

Viscoelastic behaviour also causes an energy loss during a stress-strain cycle either in extension or compression. The return curve of such a cycle is always lower than the outgoing curve. The difference between these two quantities is equal to the energy lost during the return cycle. This energy loss or mechanical damping called HYSTERESIS and appears as heat in the rubber.

The rate of this heat generation depends upon two kinds of parameters or variables. One of these is concerned with the roll covering and the other with the operating variables.

## ROLL COVERING VARIABLES

(a) Cover composition:—The rubber technologist must have the fullest details of working conditions of the roll to find the best composition to minimise hysteretic loss.

(b) Cover hardness:—Greater hardness restricts deflection of the roll under load because of greater rigidity. Compatible with requirements, harder rolls will, therefore, produce lesser hysteritic loss.

(c) Cover thickness. Since thickness of elastomeric roll covering influences the amount of deflection under load, changes in thickness should reflect in rubber operating temperature. In addition, thickness will affect the heat transfer through the covering. Thus lesser the thickness, the lower the operating temperature of a roll.

## OPERATING VARIABLES

(a) Roll speed:—It determines the frequency of flexing and therefore influences heat build-up in the rubber. Higher the speed, greater is the heat generated due to greater hysteresis.

Speed could be altered by changing the diameter of the roll as it is the surface speed of the roll that matters.

(b) Roll pressure:—Deflection will increase with enhanced loading. To maintain uniformity of deflection all over the surface, proper cambring and alignment are necessary to avoid localised pressure concentration.

(c) Roll cooling:—Removal of heat at a higher rate than natural condition would be useful in resulting in a lower running temperature. This is important for rolls running in such positions as the M. G. pressure rolls. Installing of cool water sprays over the rolls helps considerably in prolonging the life of the rubber rolls.

## MAINTENANCE OF RUBBER COVERED ROLLS

Proper maintenance of rubber covered rolls has quite a bit to do with the operation of the roll. Most problems which arise with rubber covers have their roots in the operation. True some do arise from storage and grinding also. But these are such as can be tackled more easily.

Some of the important factors affecting the rolls have just been discussed. Perhaps the worst thing to happen to a rubber cover roll in over-heating. Beucker points out that softening of rubber cover is rapid upto 160 to 180°F and then it slows down. Actual amount of softening will vary with rubber composition, but roughly from room temperature to 160°F, it will be 1 point P&J for every 10°F. Harder rolls soften less. Between 160 and 250°F difference is 3 to 5 points. With increased softness, the nip broadens giving the deflection characteristics of the roll cover as a whole. **Fig. 3** shows the dependance of nip width on temperature for 12½ in. diam. rubber roll against 12 in. metal roll. 202 pli.

The rubber compound, however, becomes more resilient with heating up. A hot roll marks the web less than a cold roll. This proves an advantage at the sizing press where cold start-up causes wad marks and dents.

With rise in temperature strength of the compound goes down.

Oxidation leads to surface or skin hardening, resulting in crazing or fine cracks. This is a surface phenomenon and grinding of the surface not only eliminates the cracks but also restores original hardness.

Heat hardening proceeds much more slowly in the absence of air than in its presence. Therefore, rubber covers of conventional polymers, from the heat ageing standpoint, give good service except when temperature conditions are very severe.

A fact of great importance is that the adhesion of rubber to the iron core of the roll decreases considerably with increasing temperature.

**Fig. 4** shows the shear strength relation with temperature for hard rubber to metal bond (R. T. = room temperature).

**Fig. 5** gives the fatigue results on a natural rubber cum vulcanisate.

## CRACKING

The normal type of flex cracking which rsults from coming too close to or exceeding the ultimate elongation of the rubber is a crack which is parallel to the axis of the roll. Another characteristic of this crack is that when it appears, it appears in large numbers. If strain is kept below the minimum value, flex crack does not occur. That is, if a compound will exhibit cracks at say 500 pli. it will do so in an extremely short period. The same compound could be run at 450 pli. with no flex cracks for quite some time .

If cracks occur in bands around the roll (but not all over), it indicates uneven loading across the face of the roll. And where there are the cracks, these are places of excessive loading.

Rolls also develop cracks rapidly when cold water is sprayed on hot rolls during shut downs. Some times rolls are allowed to run without paper when these get heated up. Spraying cold water on these rolls is harmful This is especially important for hard rolls.

Another type of cracks occur when wads go through the nip of a roll. These cracks occur in nests and have a jagged outline, like a streak of lightening. Wads cause the entire load to be carried on a small area. Hence this type of cracks.

## ADHESION FAILURE

One cause of adhesion failure is improper bonding of rubber layers on the core of the roll body during the course of building the rubber cover. This has already been mentioned .

Another reason for this failure is the hysteresis heat. If the interface temperature of the two rolls is kept below 160°F this failure occurs seldom.

## BOUNCING AND CORRUGATIONS

These are mostly due to faults in couplings, bearings, moving mechanical parts, felt seams, etc. And rarely due to rolls themselves. But if a roll corrugates, it is too soft and should be replaced with a harder roll.