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A REVIEW OF RECENT DEVELOPMENTS IN WARP SIZING

by J F McMahon and G H J van der Walt

CHAPTER 1

INTRODUCTION

The function of sizing is to improve weavability by protecting the warp yarns from abrasion in the healds and reed and against each other, strengthen them, and, by addition of oils and fats, lubricate them¹. The main consideration is to minimise the effect of hairiness, knots, crossed ends, slubs and weak spots. Therefore tensile strength, fibre-to-fibre adhesion, flexibility, elasticity and elongation are all factors to be considered in selecting sizing materials and method of application².

Historically, starch has been used as the primary size ingredient³. As production methods improved with the introduction of high speed shuttle looms and eventually the modern shuttleless weaving machine, improved sizing materials were required. This led to the development of chemically modified starches and new synthetic polymers. The introduction of these materials resulted in improved fibre-to-fibre adhesion^{4,5}, easier splitting of warp ends⁶, improved weavability⁷, easier desizing⁸, and reduced ecological pollution^{3,9}. This new generation of materials include acrylic, polyvinyl alcohol and polyester sizes. They have been discussed by Cappelle and Leigh¹⁰.

Conventional sizing has seen the introduction of techniques to improve the quality of the sized warp yarn. These include measures to reduce hairiness¹¹⁻¹⁴, wet splitting¹⁵, single-end sizing¹⁶⁻²⁴ and computer control²⁵⁻²⁹ of the sizing process. Innovative techniques have emerged such as dye-sizing²⁸, indigo dye-sizing^{28,30}, and simultaneous application of size, dye and a thermosetting resin by a process known as the Milnersized System²⁸. Ecological and economic reasons have necessitated the introduction of size reclamation³¹⁻³⁴ in many parts of the world.

More recent developments in sizing technology have centred around the need to reduce energy consumption. The sizing process requires a considerable amount of heat energy, as much as 77% of which is used to dry the yarn of residual moisture after it leaves the size box³¹. Various ways of reducing warp drying costs, whilst retaining conventional machinery have been discussed^{29,31-38}. However, there are definite limits to what can be achieved in this direction¹⁰, and the latest ideas on energy saving relate to reducing or completely eliminating the warp's residual moisture. This led to the develop-

ment of new sizing processes such as high pressure sizing^{10,17,27,31,33-35,37-51}, solvent sizing^{38,52-54}, hot melt sizing^{9,10,17,25-27,31,33,38,39,43-47,49-51,53-87}, foam sizing^{10,33,34,36,37,43,47,48,51,56,60,65,88-113}, low add-on sizing¹⁰ and the Cutts sizing system^{55,114}.

This report presents a review of some of these non-conventional systems, concentrating specifically on:

1. High Pressure Sizing
2. Hot Melt Sizing
3. Foam Sizing.

CHAPTER 2

HIGH PRESSURE SIZING

2.1 INTRODUCTION

The concept of high pressure sizing originated in France around 1974⁵⁵. Escalating energy costs rekindled interest in the technique and, pioneered by Westpoint, high pressure sizing has become an established method adopted by many major size machine manufacturers^{25,46}.

The basic idea of high pressure sizing is to reduce the amount of water to be evaporated from the warp sheet by using increased quetch pressure at the size-box. In conventional sizing, wet pick-ups of 100-120% are normally encountered³⁵. Through a high pressure squeeze roller system, however, the wet pick-up can be reduced³⁵ to 50-60% giving substantial savings in drying costs^{46,115-117}.

This decrease in wet pick-up will necessitate an increase in size liquor concentration if the same level of dry size add-on is desired^{35,39,115,116,118}. This relationship may be expressed as follows:

$$\% \text{ wet pick-up} = \frac{\% \text{ dry size add-on} \times 100}{\% \text{ solids in size-box}}$$

Typical squeeze roller loadings for high pressures sizing are normally of the order 490-608N/cm as against 18-35 N/cm typically encountered in conventional sizing^{35,49}. Before operating with pressure of such magnitude the following requirements must be met¹¹⁹:

- (a) Uniform distribution of the squeeze pressure over the whole width of the warp.
- (b) Constant squeeze effect over the entire speed range.
- (c) Avoidance of damage to yarn and knots when working with increased pressure.

2.2 THE HIGH PRESSURE NIP

When a relatively large force is applied to the squeeze rollers it results in extremely high specific pressure at the nip of the rollers, which can exceed conventional size pressures by a factor of 20⁴⁹. Therefore, certain considerations are necessary when dealing with high pressure systems.

For high pressure sizing a more strongly constructed size-box is required¹²⁰. Attempts to modify conventional size-boxes would result in damage to the roller joints, bowing of the rolls and variation in pick-up across the warp sheet²². An evaluation must also be performed on the mechanical drive to the size-box to ensure that adequate capacity is available for reliable performance³⁹.

Increased power^{22,26} is required for driving the high pressure rollers and necessitates increasing the motor rating from 0,75 kW to 3,75 kW²².

The hardness of the roller coating will determine the width of the nip (Fig. 1). The latter influences the magnitude¹¹⁵ and duration of the axial stress of the warp sheet which is due to the yarns deforming according to roller deformation. Research at Reutlingen¹¹⁵ has shown that different roller coatings exhibit different characteristics but generally the width of the nip

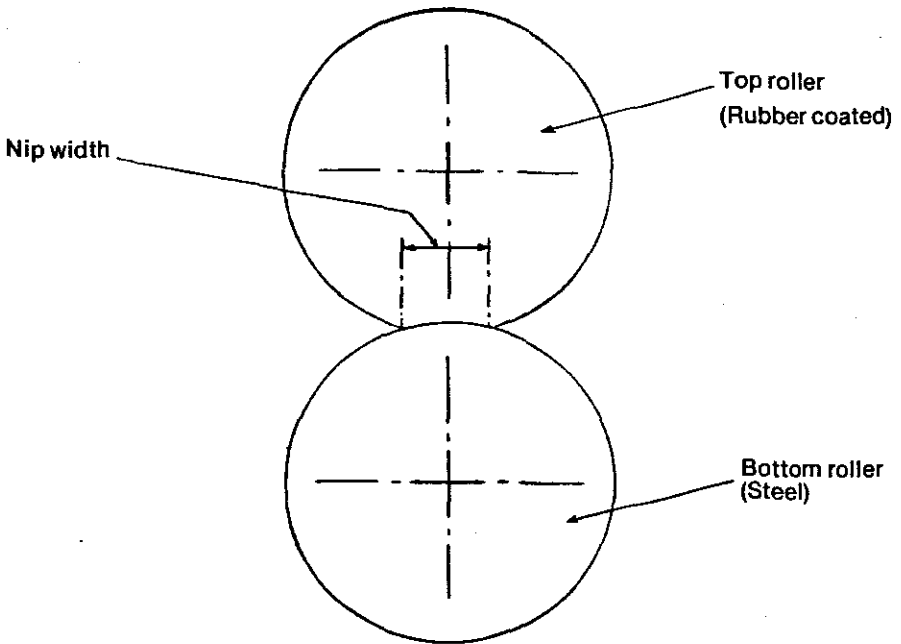


Figure 1 — Squeeze Roller System

increases linearly with roller loading up to a squeezing pressure of 300N/cm; further increases in squeeze pressure has less influence on nip width. As might be expected, the width of the nip increases with roller pressure¹¹⁵. (Fig. 2).

High specific pressures also present the question of their effect on load distribution within the nip. Squeeze rollers deflect when loaded resulting in a variation in the width of the nip^{121,122}. This results in varying squeeze pressure and yarn residence time in the nip along the roller face. These variations cause inconsistent size add-on to the yarn from selvage to centre of the warp sheet (Fig. 3).

Investigations at Westpoint¹²² have shown that the variation in size add-on due to roller deflection is not significant in the case of narrow size boxes. However, on wider size boxes of 1,4 metres yarn web width or more, corrective action is necessary by way of "crowned" squeeze rollers.

A squeeze roller is crowned by grinding the rubber cover to a larger diameter at the centre of the roller face than at the edges. The exact profile of the roller face is critical and requires precise grinding of the rubber cover to maintain a uniform nip width. Furthermore, the amount of crown required is dependent on roller construction, dimensions and desired squeeze loading. For

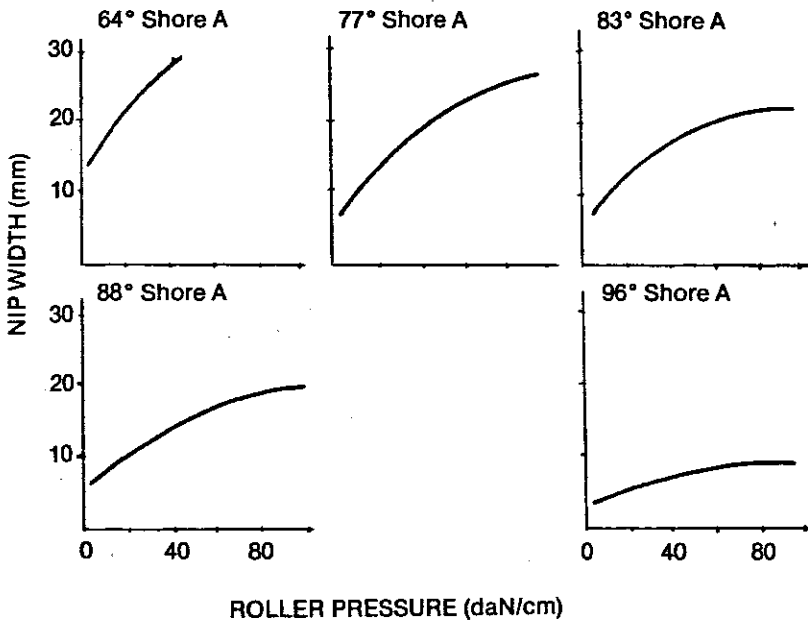


Figure 2 — The Effect of Roller Pressure on Nip Width¹¹⁵

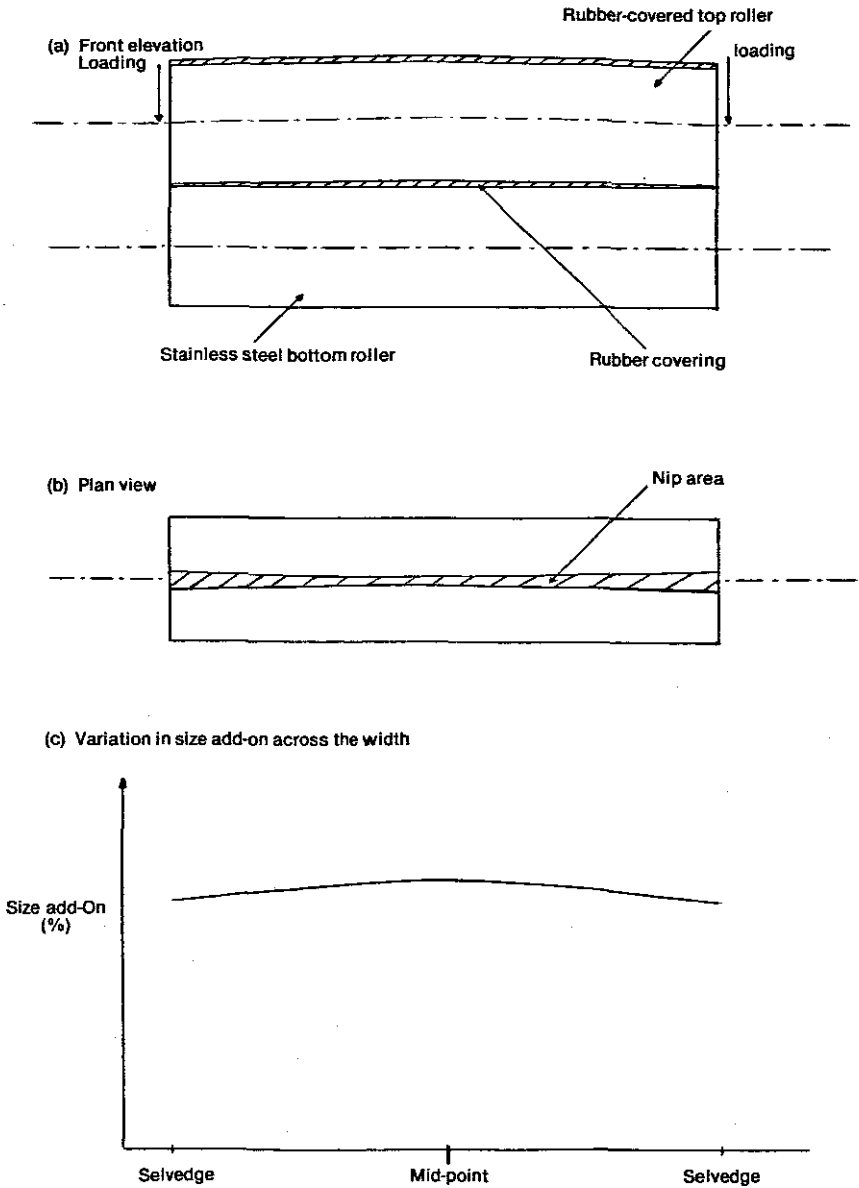


Figure 3 — Deflection of Roller System

example, Westpoint¹²² quote the following specifications for their Model 789B system:

Warp width — 1 830 mm
Crown — 0.61 mm
Roller loading— 6 327 kg

A disadvantage of crowned rollers is that the nip impression is only uniform at the specified roller loading. The system, therefore, cannot be operated at lower or higher pressures¹²². Periodic regrinding of the crowned squeeze rollers can be complicated and requires precise calculations to produce an even nip impression. Westpoint perform this task using computerised equipment.

2.3 SIZE APPLICATION BY HIGH PRESSURE SIZE-BOX

2.3.1 Machinery

High-pressure squeezing has become an established practice, with many of the machinery manufacturers exhibiting units at ITMA '83.

Barber Colman²⁵ offered a unit featuring large diameter squeeze rollers (to minimise deflection) with roller loading up to 90 kN. Westpoint^{25,27} use a covered top roller and stainless-steel bottom roller with a loading of 90 kN. Sucker^{25,122,123}, opted for roller loadings¹²³ of 100 kN and introduced a new rotary cooker⁴² specifically designed for high pressure sizing. Zell's Ecopress size box^{25,27,41} offered loadings of 97 kN. Platt²⁵ introduced a unit with roller loadings of 60 kN.

It is interesting to note that many manufacturers introduced medium pressure size boxes using roller loadings of 18—27 kN. Chadwick²⁵ explains that this alternative has been offered in the light of mill experience with high-pressure sizing, where the theoretical benefits of energy saving have not been attained in the long term, due to breakdown of nip roller coverings and problems with highly concentrated size formulations which this system requires.

2.3.2 Size materials

High-pressure sizing demands an increase in the percentage solids in the size box, and this is limited by the need to maintain a sufficiently low viscosity to allow proper penetration and encapsulation of the yarn^{39,115}. Another limitation imposed is that, at higher viscosities, an increase in yarn tension is required in the size box to straighten crossed ends¹¹⁵, leading to excessive stretch. This led to the development of new size materials with suitable rheological properties at high concentrations.

A number of low viscosity products have been derived from starch. These include oxidised potato starch, in-vacuum depolymerised potato starch, acetylated potato starch and hydroxypropylated potato starch. These products have been discussed by Manguin and Ansar¹²⁴.

Du Pont⁴⁶ have developed two new grades of PVA (polyvinyl alcohol), of intermediate viscosity and intermediate hydrolysis. They claim energy savings of 40—50% if their products are used with a high pressure size system.

Seydel⁴⁶ have developed a modified PVA co-polymer and a highly modified polyester resin. Their research is concentrating on polyester resins with 75% solids content requiring no cooking, and easily blended with starch, PVA and CMC (carboxymethyl cellulose).

Seydel claim that with combinations of polyester resin and acrylic co-polymer, energy savings of 22—24% were realised, and sizing speeds increased by 80%.

2.3.3 Performance of the system

2.3.3.1 Yarn properties

- (a) **Yarn flattening:** When the warp passes through the high pressure nip, *extreme flattening of the individual yarns must occur*. Trauter and Böttle¹⁵, using photographic techniques and a simulated nip, have investigated this flattening effect.

According to the results of their experiments¹⁵, the warp yarns become increasingly flattened with increasing load until a final yarn width is reached. This terminal value depends on the nip width. The deformation is mostly elastic as the yarn regains its original shape, to a great extent, when the load is removed. The residual deformation is almost independent of the load, but greatly dependent on the width of the nip.

It was concluded from these results, therefore, that since the permanent deformation is mainly influenced by the width of the nip, high-pressure squeezing is unlikely to increase yarn flattening if the nip width is similar to conventional sizing.

This can be achieved by careful selection of roller hardness¹⁵, as shown in Fig 4.

On the other hand, studies by North Chemical Company and Auburn University¹²⁵ indicate that excessive squeeze roller pressures can cause undesirable cross-section distortions on some yarns. The workers used scanning electron microscopy to evaluate yarns sized at 13,8; 27,6 and 34,5 N/cm² squeeze-roller pressures. These studies show that as the squeeze-roller pressure increased, the yarns became increasingly oval and distorted in shape. This was due to excessive size penetration cementing the yarn bundle together thus eliminating the interstitial spacings between individual fibres. The severity of this problem appears to increase with greater yarn diameters. The workers advise that squeeze roller pressures must be carefully selected for a given yarn, or poor sizing will result in reduced weaving performance.

- (b) **Tensile strength:** The measurement of tensile strength will give an indication of yarn damage¹¹⁵. Research, using 96° shore rollers and 100 kN loadings¹¹⁵, has shown that tensile strength of sized yarns is not significantly reduced by the high-pressure nip. The tensile strength of yarns containing knots is reduced more than the tensile strength of yarns without knots, but not significantly so.
- (c) **Abrasion resistance:** Early results indicated that the abrasion resistance of sized yarns is reduced by 40% when employing the high pressure squeeze³¹. Other results¹¹⁶ suggested, when hard rollers are used, that there is an increase in abrasion resistance and that when soft rollers are used there is a decrease in abrasion resistance. More recent work¹¹⁵ has shown that most yarns sized with high pressure squeezing are 30–40% more abrasion resistant than yarns conventionally sized, possibly due to the high pressure

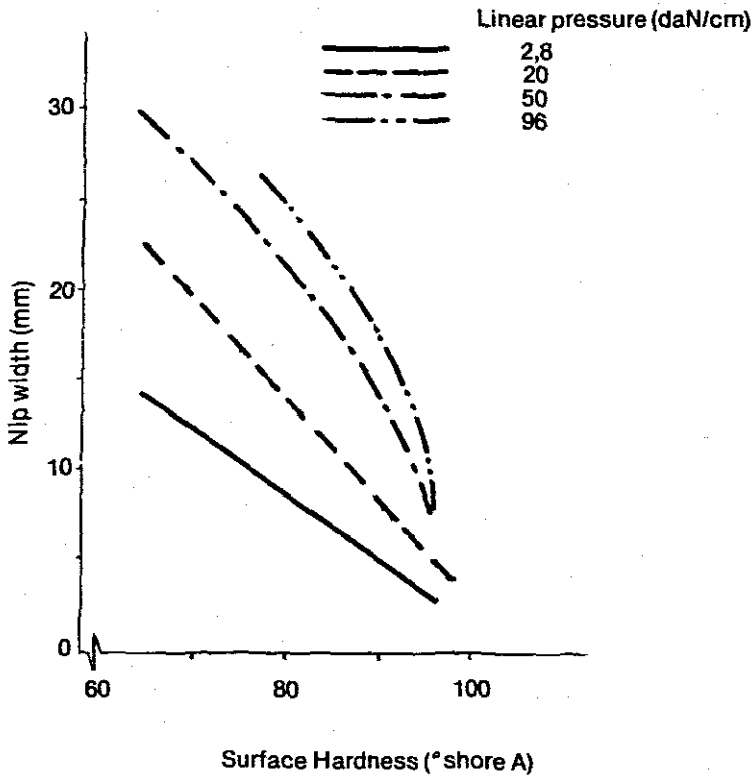


Figure 4 — Effect of surface hardness on nip width¹¹⁵

increasing adhesion between size and the fibres, thus improving the surface coating of the yarn¹¹⁷. Some further evidence of improved abrasion resistance was obtained by Bevaloid (S.A.) during laboratory trials¹⁰. On the other hand; the researchers at Auburn University¹²⁵ showed that high-squeeze pressures can cause excessive size penetration. This leaves an insufficient size covering on the yarn surface to protect against abrasion and other weaving stresses.

- (d) **Hairiness:** Research at Reutlingen¹¹⁵ showed that high pressure squeezing has no significant effect on yarn hairiness, although American mills claim that a decrease in hairiness was observed during industrial trials³⁵.

2.3.3.2 Mill and Laboratory Trials

Trials conducted in 1978 by Westpoint³⁹ showed steam savings, higher sizing speeds, improved weaving performance and potential reduction in sizing product costs. It was claimed that this system promoted better penetration of the size, a stronger fibre bundle, and improved fibre lay.

More recent trials agree with these results. According to Ruddick¹²⁶, the reduction in water to be evaporated can be 50% at loadings of 90 kN and at speeds of 80—100 m/min, with wet pick-ups of the order of 65%. Drying costs have been reduced by as much as 40% in some mills. Becker¹²⁷, reporting practical experience, claims energy savings of 20—30% are possible when sizing staple-fibre yarns.

Research at the South African laboratories of Bevaloid, at squeeze-loadings of 35 to 70 kN, indicated potential reductions in drying costs of up to 37%, at size add-ons between 7 and 11% solids, the lowest wet pick-up being 68%¹⁰.

Zell¹¹⁹, with over 30 high pressure heads in commercial operation for several years, have reported the following advantages:

- (a) An increase in productivity of the sizing plant of 25—35% can be achieved on medium and heavy warps with no alteration in steam consumption. It was also possible to operate at reduced steam pressures during the sizing of the light articles, resulting in a possible saving of up to 20% in steam.
- (b) Savings of up to 10% in sizing ingredients can be achieved.
- (c) Generally, low viscosity sizes with low shearing ability present no problems.
- (d) A reduction in damage to the ends and knots of the warp, by using a special rubber covering for both top and bottom rollers, having a particular modulus of elasticity.

Trauter and Böttle⁴⁰ have discussed the limitations of high pressure squeezing. The effect of squeeze roller parameters such as nip pressure and roller hardness on size add-on and the water uptake were found to limit the maximum reduction of water uptake to 55—60%. Possible savings are higher, the lower the warp density and (with limitations) the higher the warp speed.

The system has been reported to perform well with spun and filament yarns. Short staple spun yarns require more cleaning and filtering of size⁴⁵, possibly due to some removal of fibres from the yarn by the compressive action of the rollers.

An evaluation by Trauter³¹ of the potential savings by high pressure squeezing for a warp yarn production of 10⁶ kg per year is given in Table 1. It is clear from the evaluation that there is potential for a substantial saving in steam cost by using high-pressure sizing.

The payback on investment of a high pressure system has been estimated to be 4—5 years³⁷.

TABLE 1³¹
POTENTIAL SAVINGS BY HIGH PRESSURE SQUEEZING

Size Add-on %	Conc. Size Liquor %	Wet Pick-up %	Water 10 ³ kg	Δ W 10 ³ kg	Δ St. 10 ³ kg	Savings* for steam \$	Additional costs \$/year		Total Saving \$
							Power	Capital Costs	
10	8	125	1150	536	750,4	12 500	220	2 200	10 000
	14	71	615						
18	12	150	1380	742	1038,8	17 300	300	3 300	13 700
	22	82	638						

*Based on yarn production of 10⁶ kg/year and steam cost of \$1,67/1000 kg for drying.

ΔW = Difference in water take-up

ΔSt = Difference in steam required.

CHAPTER 3

HOT MELT SIZING

3.1 INTRODUCTION

Hot melt sizing is a method of sizing a large number of yarns being advanced in sheet form, with a size which contains a wax component. The size is in a solid state at room temperature and in a liquid state at a substantially evaluated temperature above room temperature. The concept involves coating a heated roller with the size in liquid form, regulating the quantity of size adhering to the heated roller, and making contact between the warp sheet and the peripheral surface of the heated roller.

The idea of hot melt sizing was patented¹²⁸ in 1969 by Kawamoto Industrial Co Ltd of Japan and in 1971 the American industry became interested in the method. Sydel-Wooley Co. carried out some research in this area and Livengood¹²⁹ refers to a prototype machine operating at 450 metres/min. Burlington Industries¹² combined the concept with their patented grooved roller technique. Westpoint Foundry and Machine Company²⁵ were assigned worldwide sales and production rights and continued development has led to the introduction of a commercially available unit, exhibited for the first time at ITMA '83.

The Burlington/Westpoint apparatus is currently the only available machinery for hot melt sizing and as such, this review concentrates specifically on this unit.

3.2 METHOD OF APPLICATION

The Burlington/Westpoint method of hot melt sizing is accomplished during the warping process by the application of the molten 100% active size material to the warp yarns. The hot melt applicator is located between the warper creel and the warper. The process can be carried out at conventional warper speeds.

The major component of the apparatus is a grooved applicator roller, of approximately 1,5 metres in diameter¹³⁰. This is uniformly heated to about 200°C and rotates at approximately 10 rev/min in the same direction as the warp sheet³¹ (Fig 5). The hot melt size, in the form of a solid block, is supported by a table at the 8 o'clock position and pressed pneumatically or hydraulically against the hot roller¹³². The size melts and fills each groove with molten size^{69,87}.

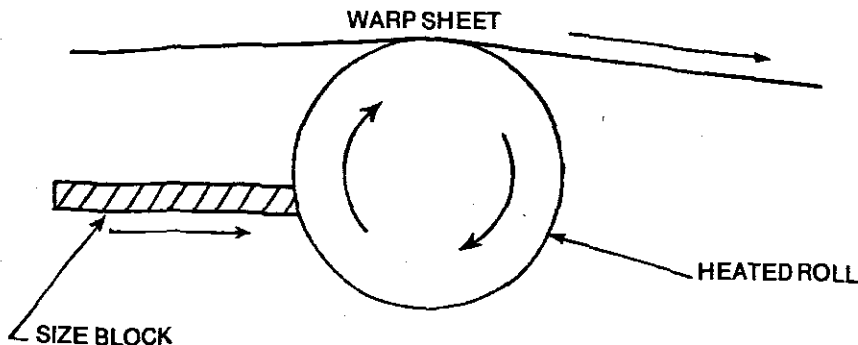


Figure 5 — Diagram of Hot-melt size applicator¹³⁰
(Side view)

Each end of the warp sheet is located into an individual circumferential groove on the roller (Fig 6), making contact for an arc of 1–2 cm depending on machine setting⁵⁸. The grooves are 3–5 times greater in depth than the yarn diameter¹³⁰. The warp yarns travel through the grooves at a speed of about 600 metres/min, considerably higher than the 4,5 metres/min surface speed of the roller¹³⁰. The relative speeds of the yarn and roller are such that a differential friction force is built up between the surface of the yarn and the inner wall surface of the groove¹². This furnishes a type of wiping action on the peripheral fibres projecting from the surface of the yarn so that they are caused to be laid down¹². The size completely coats the yarn surface and as the yarn continues into the surrounding cooler air, the size solidifies very quickly, bonding the fibres together.

There is a single end reed which holds the yarn down into the grooves during sizing but raises it out of contact when there is an end break. Additionally, the whole unit is mounted on rails and automatically moves a metre or two towards the warper after an end break and repair to ensure there are no unsized patches going through¹³².

The hot melt sized yarn is wound onto a warper section beam and re-beaming the warper section beams onto a loom beam is the final step^{87,131}.

Westpoint^{69,87,131} claim that this technique offers several advantages, such as:

- (a) Low energy consumption.
- (b) Elimination of size cooking and disposal.
- (c) Greater speed of size application — the rate of application is determined by the rate at which the size solidifies to a non-tacky or non-blocking state.

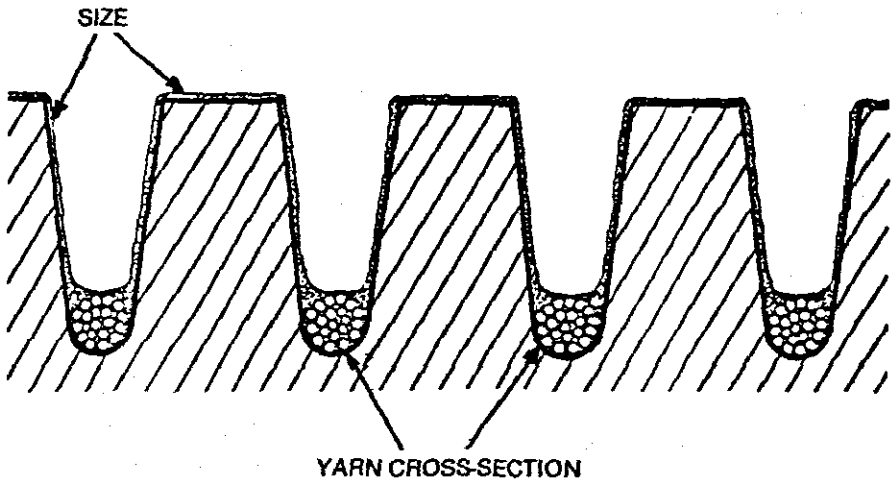


Figure 6¹³⁰ — Cross-section of applicator roll

Trauter¹¹⁶, however, discussed the effective speed of the unit taking into consideration the entire operation. He estimated that for a 20 000 metre warp, the production rate would be 23,7 metres/min for hot melt sizing and re-beaming, and 26,8 metres/min for warping and conventional sizing. Another point raised by Trauter¹¹⁶ is that hot melt sizing could lead to high water contamination at desizing.

3.3 SIZE MATERIALS

Hot melt sizes may often be constituted predominantly of waxes or wax-type products, but according to Westpoint¹³¹, it is incorrect to classify these products as waxes. They list the following requirements for products to be suitable for hot melt sizing^{87,131}:

- (a) Melt temperature 125 — 155°C
- (b) Low melt viscosity
- (c) Immediate set-up time
- (d) Suitable properties of size film, such as tensile strength and elongation
- (e) Resistance to heat degradation
- (f) Resistance to blocking
- (g) Acceptable costs
- (h) Conventional aqueous desizing.

Eastman Kodak Co. of New York, have patented a number of compositions suitable for use as hot melt textile warp sizes^{62,70,72,73,86}. These products are generally prepared by blending co-polymers of ethylene and acrylic acid and methacrylic acid, with selected additives of low-molecular-weight. These blends have low melt viscosities, can be readily applied with conventional hot melt sizing equipment and set-up rapidly to provide non-tacky protective coatings on the yarns. They can be easily removed using conventional aqueous desizing.

Burlington have patented a number of hot melt size products^{57,66,72,73,78}. Their most recent composition⁵⁷, for example, contains substantially more hydrogenated tallow or equivalent triglyceride wax than hitherto tolerable in textile melt sizes. Burlington's experience in the field of hot melt sizing has shown that a fine balance exists between the need for relatively high melting point and application temperatures, (to help ensure rapid solidification on the yarn), and the need to prevent, or at least minimise, the tendency for the hot melt size to fume, smoke or gel on the applicator roll. They attribute the outstanding performance of their product to the unusually high content of hydrogenated tallow. Burlington's size compositions are highly resistant to tackiness, and can be applied at much higher add-ons (8—18%) than most hot melt sizes⁵⁷.

3.4 PERFORMANCE OF THE SYSTEM

3.4.1 Controlling parameters

Size add-on and the degree of fibre lay can be controlled mechanically¹³¹. The main considerations are the quantity and viscosity of size applied to the yarn and the yarn/roller-surface differential speed¹³². These parameters may be controlled by consideration of the following factors^{87,131}:

- (a) Applicator roller speed
- (b) Arc of contact
- (c) Applicator roller temperature
- (d) Warp yarn speed
- (e) Feed rate of size application to the grooved roller.

Eastman Kodak Co.¹³⁰ have carried out some research in this area using a polyester/adipic acid size product similar to that described in the literature⁷². The main conclusions from their work were that size add-on was significantly influenced by yarn speed, roller speed and size feed rate. Size add-on was found to be independent of roller temperature and groove diameter for the conditions of the investigation¹³⁰.

Although it is not clear to what extent the groove size affects the size add-on, the groove depth, however, plays an important part in the process and this can limit the range of yarns that can be sized^{87,131}. Burlington claim^{87,131} that by using three rollers each with a certain groove size, the applicator can handle spun yarn from 12 tex to 115 tex.

3.4.2 Yarn Properties

The first point to be considered is the effect of the high (200°C) temperature on the yarn. Experience has shown that dye affinity and heat history of the yarn remains unaffected due to the extremely brief contact time^{69,131}. For example, at a yarn speed of 550 m/min with 1,2 cm arc contact, contact time has been estimated to be 0,008 seconds⁵⁸.

Experiments¹³³ at Burlington showed the specific yarn characteristics of hot melt size yarn to be as follows when compared with conventionally sized yarn:

- (a) Yarn strength is not impaired by hot melt sizing.
- (b) Residual elongation is higher with hot melt sized yarn.
- (c) Yarn stiffness is lower with hot melt sized yarn and so the yarn is more flexible in weaving.
- (d) Yarn friction is lower than conventional sized yarn.
- (e) Yarn compression is higher resulting in a denser weaver's beam than starch derivative sized yarn.

Experiments conducted by Seydel Wooley Co¹²⁹, Westpoint¹³⁰ and at Reutlingen³¹ showed that the hairiness of hot melt sized yarns was considerably lower than that of conventionally sized yarns. The decrease in protruding

fibres was approximately 95—98% in the case of the Reutlingen experiments³¹.

Regarding the abrasion resistance of hot melt sized yarn the situation is not so clear. The experiments at Burlington¹³³, Westpoint¹³⁰ and Seydel Wooley Co⁵³ showed the abrasion resistance to be higher than conventionally sized yarn. However, the work at Reutlingen³¹ showed the abrasion resistance of hot melt sized yarns to be 40% lower than that of yarns conventionally sized with PVA. Further work in this area is obviously required.

3.4.3 Weaving Performance

Westpoint^{54,55} report that extremely successful weaving trials have been carried out with several different yarns in several traditional constructions. They emphasize the reduction in shedding achieved due to the excellent elastic properties of the hot melt size yarn^{58,85}. In weaving trials (percale sheeting) using 28 tex 50/50 polyester/cotton yarn, the ends down were reduced by 60%.

There would appear to be no independent weaving trials reported in the literature. However, researchers of the University of Bradford have conducted some investigations into the weaving properties of hot melt sized yarns on a small scale. The work entailed hot-melt-sizing a R36 tex/2 worsted yarn with a suitable product. Ten ends of this yarn were substituted into a warp of the same yarn which had been waxed on an overwaxing unit. After weaving 100 000 picks the results indicated that the hot-melt-sized yarn was superior to the overwaxed warp yarns and the workers agreed that the hot-melt-sized system had some advantages to offer in this respect¹³².

CHAPTER 4 FOAM SIZING

4.1 INTRODUCTION

The escalating cost of energy has been an important factor in the increased use of foams in the textile industry. The recent interest in foam as a medium for size application has been due to its potential to significantly reduce wet pick-up of the size liquor and achieve large savings in drying energy costs.

The effectiveness of foam technology has successfully been demonstrated in processes such as finishing^{135,136}, dyeing^{137,138}, printing¹³⁹ and mercerisation^{140,141} of textile substrates. It is clear from the literature that foam treatments offered substantial savings in drying energy costs^{142,143} and actual savings as high as 80% were reported¹⁴⁴.

Foam sizing consists of mechanically foaming a suitably formulated size liquor, applying a predetermined amount of foam (having the required properties) to the warp sheet, and then causing the foam to collapse prior to drying. In practice, however, there are some very important parameters to monitor and control in order to achieve the objective of a uniform distribution of solid size on the yarn.

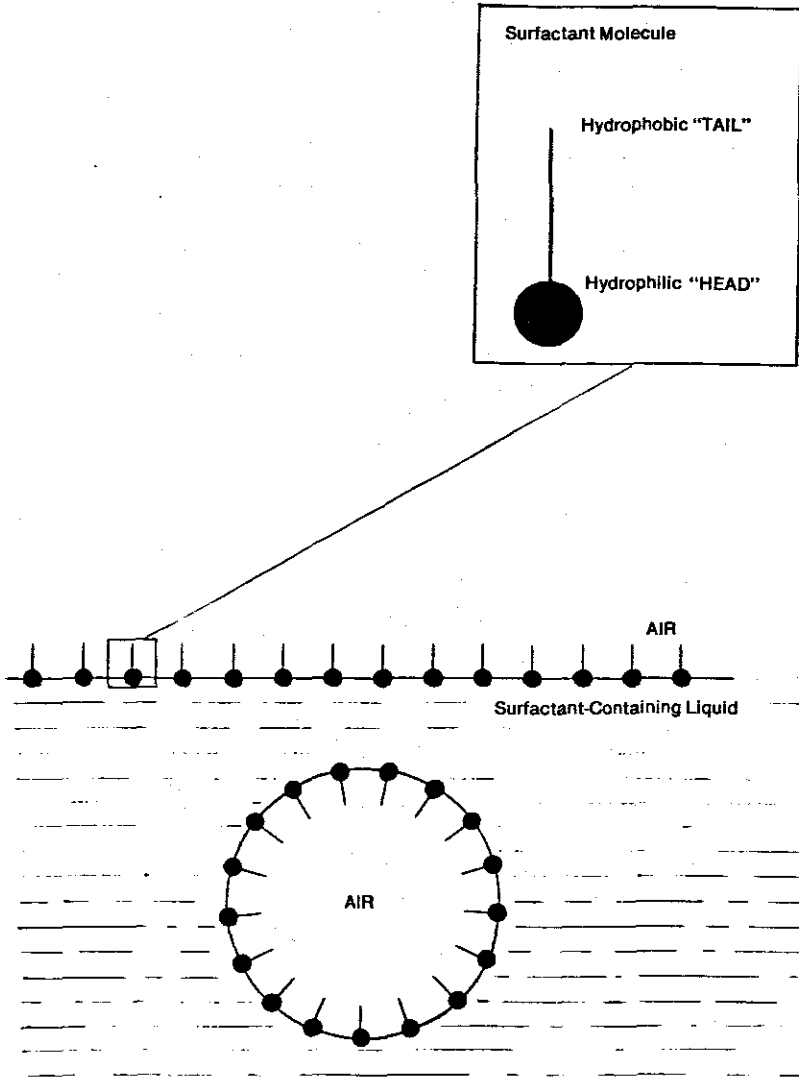


Fig 7 — Air bubble in surfactant-containing liquid

4.2 FOAM STRUCTURE

A foam is an agglomeration of bubbles of gas dispersed in a relatively small volume of liquid¹⁴⁵. The bubbles are separated by thin films of liquid and most of the volume is in the gas phase¹⁴⁶. Foams cannot be formed from pure liquids. It is essential, therefore, to have at least two components present in the liquid which is to be foamed, viz. a surfactant and a gas, for foam generation¹⁴⁵.

When a gas is introduced into a surfactant-containing liquid it forms a bubble of gas surrounded by a monomolecular surfactant film (Fig 7). The surfactant molecules will also have been positively adsorbed at the gas-liquid interface forming a surface film which differs in composition from the bulk of the liquid phase¹⁴⁷. If this surface is penetrated by the bubble, a second surface film will surround the first one (Fig 8), creating a "double skin" effect, known

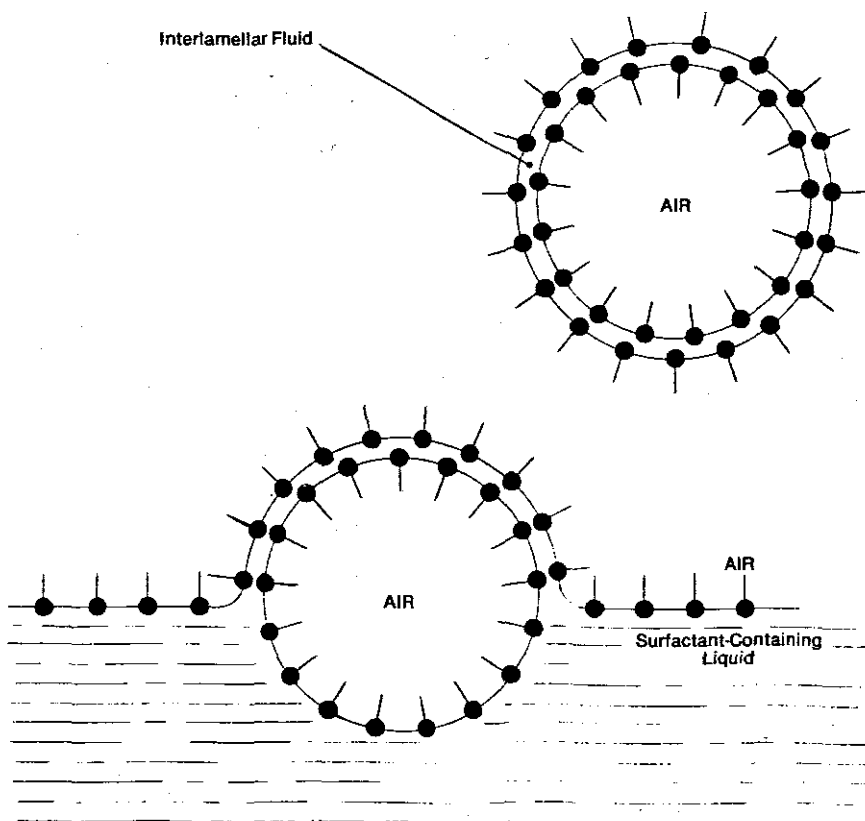


Fig 8 — Formation of foam bubble

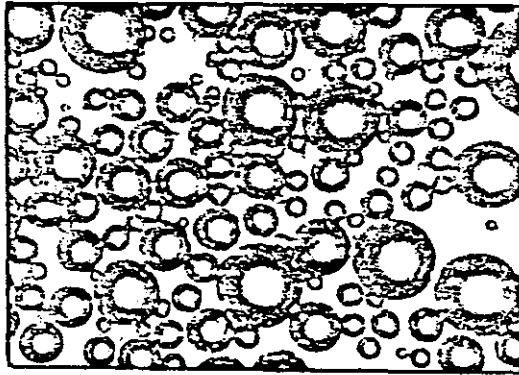


Fig 9 — Spherical bubble foam

as a foam lamella^{145,146}, containing interlamellar liquid. The foam lamella contains the chemical-containing liquid required for the subsequent wet process¹³⁵.

The collective term "foam" covers two fundamentally different morphological structures of foam, i.e. spherical foam and polyhedral foam¹⁴⁸. The spherical bubble foam (Figure 9) consists of spherical bubbles widely separated by thick liquid films¹⁴⁹. A polyhedral foam (Figure 10), on the other hand, consists of a collection of polyhedral bubbles with thin clearly defined films of liquid between them¹⁴⁸. From a thermodynamic point of view the foam phase is not stable and all foams tend to collapse eventually. In the case of a spherical foam, (also termed 'unstable foam'), the foam collapses immediately after foaming has stopped, due to the flow (drainage) of the liquid in the foam lamellae. The rate of drainage is affected by density, viscosity and film thickness. If a foam has not drained, the lamella is relatively thick and the bubbles are spherical.

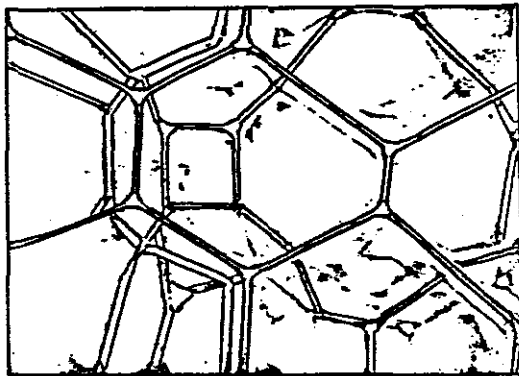


Fig 10 — Polyhedral bubble foam

In the polyhedral (metastable) foams, on the other hand, the drainage of liquid is slowed down at a certain stage, prior to the collapse of the foam, depending on the stability of the lamella. There are several factors which affect the stability of foams, such as surface tension, viscosity, surface area, temperature, pH and concentration of the surfactant¹⁴⁷. Apart from the fact that a low surface tension is required, one of the most important factors which affect the stability of a foam is drainage.

Drainage occurs when the liquid in the lamellae drains away due to gravity or the Laplace effect causing the lamellae to become thinner. This effect, however, is somewhat counteracted and retarded by the Marangoni effect^{147,150}. When the liquid in a lamella flows from the upper to the lower portion of the bubble, the concentration of surfactant at the top of the bubble decreases, while it increases at the bottom. The resultant difference in surface tension causes the interfacial layer surrounding the bubble to move upward. An equilibrium or metastable state arises. Foams which are normally used in textile applications are of the metastable type. The specific properties, such as the density, viscosity and stability of the foam are normally determined by the particular foam application technique employed.

4.3 FOAM PROPERTIES

Due to their unstable nature, the properties and the behaviour of foams during application depend on a wide variety of factors. It is essential that foams with the required properties be selected for each application process and for the type of substrate to be treated. The most important characteristics of a foam are density, viscosity, stability and bubble diameter¹⁵¹.

4.3.1 Foam Density

Foam density is measured more frequently than any other property of foam and is defined as the ratio of the mass of the foam to the volume of the foam, i.e. the higher the volume of air, the lower the foam density. Instead of foam density, a related quantity, namely expansion or blow ratio, is often used in practice. This is defined as the ratio of the mass of the volume of foam to the initial volume of liquid before foaming¹⁵². For textile applications, foams having densities in the range of 0,33 g/cm³ to 0,005 g/cm³ (blow ratio 3 : 1 to 200 : 1) are normally used^{153,154}. In foam sizing, densities varying from about 0,37 g/cm³ to 0,04 g/cm³ (blow ratios 3 : 1 to 25 : 1) have been used^{94,95,103}.

In the case of foam application systems where foam density is used to control the wet pick-up, a decrease in foam density will result in a decrease in the wet-pick-up^{155,156}. In certain other foam application systems, however, the selection of the density of the foam may depend on the fabric mass, requiring the foam density to be increased when the mass of the substrate increases¹⁵⁷. If the foam density and the concentration of the original liquid are known, it is possible to calculate the quantity of solids per unit volume of foam.

4.3.2 Foam viscosity

The viscosity of a foam is, *inter alia*, a function of foam density^{94,103,158,159} and the viscosity of the unfoamed liquor⁹⁵. Increasing the viscosity of the unfoamed liquor or decreasing the foam density (Fig 11) will result in an increase in the viscosity of the foam. Viscosity also depends on the size of the bubbles. As the bubble size increase, foam viscosity decreases^{94,159,160}.

In the foam sizing process, it was reported that spun yarns needed a relatively high viscosity size. Continuous multifilament yarns, on the other hand, required a low viscosity size⁹⁴. Foam viscosities ranging from 10 mPa.s to 2 250 mPa.s are normally employed in the different textile application processes. In foam sizing, however, foam viscosities from 2 700 mPa.s to 46 000 mPa.s have been reported^{94,95}.

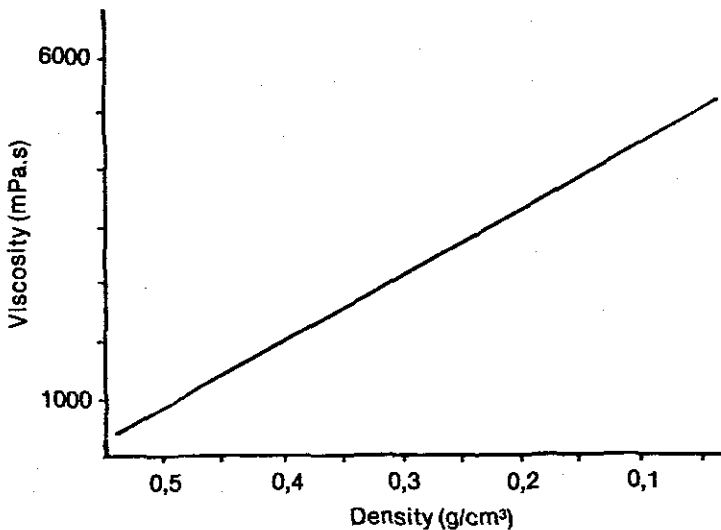


Fig 11 — The effect of Foam Density on Foam Viscosity¹⁵⁶

4.3.3 Foam Stability

The accepted measure of foam stability is the half-life ($t_{50\%}$) concept. This is the time required for half the volume of liquid contained in the foam to revert back to the bulk liquid¹⁶⁰. Certain foams will remain stable for long periods while others break immediately after formation. Depending on the particular foam application system and the specific substrate, foams may vary from a relatively low degree of metastability ($t_{50\%} = 1$ to 5 min) to a high degree of metastability ($t_{50\%} = 1$ to 5 hours)¹⁶¹. In foam sizing stabilities or half-lives of foams were reported as being higher than 80 minutes⁹⁵ to “too stable” to measure⁹⁴.

4.3.4 Bubble Size

The diameter of the foam bubble, generally referred to as the average bubble size, can be determined, for example, by taking photomicrographs of foam samples. The average bubble size of a foam depends on the particular foam application system and varies in diameter from 0,001 to 0,1 mm in some cases¹⁶² and from 10 mm to 50 mm in other cases¹⁶³.

Little or no information is available on the average bubble size of foams employed in foam sizing.

The foam characteristics required for specific foam application systems differ widely and the foam properties are often affected by a number of factors. For example, the stability of a foam is affected by the interaction of several factors. For example, the lower the surface tension of the liquid, the lower the elasticity of the bubbles and, therefore, the more stable the foam¹⁵⁰. An increase in the liquid viscosity and, consequently, the surface viscosity of the lamella, will increase foam stability¹⁵². This high surface viscosity will also retard the coalescence of bubbles and hinder the rearrangement of the bubbles, thereby increasing foam stability¹⁵². Temperature can also have an effect on foam stability, the latter generally decreasing with increasing temperature¹⁴⁷. As far as the diameter of the foam bubble is concerned, foams with a smaller average bubble size tend to be more stable than foams having a greater average bubble size^{164,165}.

Although the properties of the foam itself are very important, various other factors should also be considered when the foam is applied to the textile substrate¹⁶⁶. For example, the surface properties of the foam are very important, and depend on the surface tension and the rate of wetting of the substrate. Furthermore, rate of collapse of the foam on the substrate, and the transport of liquid in the fibres and yarns also play an important role in achieving uniform application.

4.4 GENERATION OF FOAM

Successful foam size generation requires a foaming device, a suitable medium or solvent, a size product, foaming agent/stabiliser (if necessary) and a suitable gas (usually air). The foam generator is the most important part of foam processing technology¹⁶⁷, and it must be able to produce a foam completely homogeneous as regards to bubble size and structure, viscosity and stability^{101,102,112,168}. The generator must also be capable of producing a foam of the required properties consistently¹⁶⁹.

The various methods for generating foam differ in the way the gas is introduced to the foaming liquid. The most common methods¹⁴⁶ include bubbling gas through orifices, using injectors, agitation or by other mechanical means and chemical generation of gas in the liquid. In textile operations, generation by mechanical agitation is generally employed. There

are a number of commercial machines available and these have been discussed by Turner¹⁶⁹ and by Van der Walt and Van Rensburg¹⁷⁰. These generators can be classified as either dynamic or static generator systems¹⁷⁰.

4.4.1 Dynamic Foam Generation

The dynamic foam generator usually consists of a liquid flow pump, a mixing head, an air metering unit, and a device for delivering the foam to the point of application¹⁶⁸. The actual generation of the foam occurs in the mixing head. This consists of a pressurised chamber containing a stator and rotor (see Fig 12), both of which are fitted with teeth¹⁶⁸. The teeth of the rotor are situated adjacent and in very close proximity to the teeth of the stator. When the air and liquid are introduced to the mixing head, the rotor is rotated at high velocity, subjecting the liquid/air mixture to extreme shear forces and turbulances between the stationary and moving teeth^{167,168}. The magnitude of these forces determines the foam properties, the former being controlled by factors such as the velocity of the revolving teeth, the tooth density, the shape of the tooth and the clearance between stationary and moving teeth^{92,168}. Furthermore to produce a homogenous and consistent foam it is also important to accurately meter the volume of air and liquid flow to the generator¹⁶⁷. Foams produced by the dynamic foam generator have only uniform characteristics for a set of fixed parameters^{161,165}.

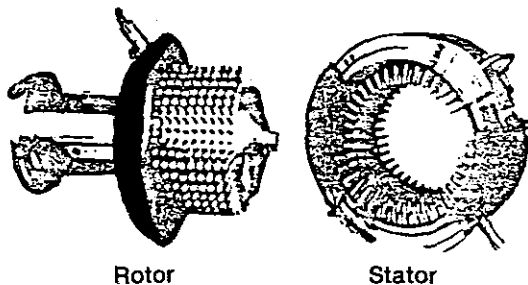


Figure 12 — Dynamic Foam Generator¹⁶⁸

4.4.2 Static Foam Generation

The principle of static foam generation involves the introduction of liquid and gas under pressure to the foam producing nozzle¹⁵⁸. The nozzle contains a tubular section with a portion of its length partitioned off by two perforated plates (see Fig 13). Between these plates are a number of spherical glass or ceramic bodies¹⁷¹.

As the liquid and gas pass through the partitioned section, their direction of movement is continuously changed by the surfaces of the spherical bodies. This inter-agitation of liquid and gas leads to a foam being produced. The properties of this foam are determined by the size of the spherical bodies¹⁷¹.

Static foam generators have the advantage of simplicity and reduced cost compared with dynamic generators¹⁷⁰. However, this system has yet to be developed and tested for use in size application.

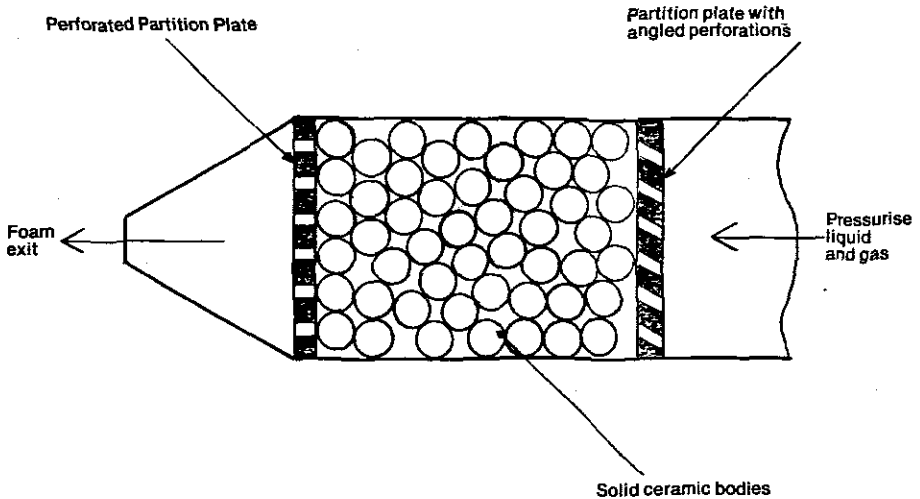


Figure 13 — Static Foam Generator¹⁷¹

4.4.3 Foamable Sizes

The foaming ability and the application of several conventional sizes by foam techniques have been investigated at Auburn University^{91,94,103,159} and at SAWTRI⁹⁵. These include sizes such as polyvinyl alcohol (PVA), partially hydrolysed PVA, cellulose and starch derivatives, carboxymethyl cellulose (CMC), polyester resins, and acrylics.

Some of these sizes foamed quite readily without the aid of foaming agents⁹⁴. The polyester resins and acrylics, for example, could be foamed quite readily to produce low foam densities with lower viscosities than the other sizes⁹⁴. Other sizes such as CMC and fully hydrolysed PVA, on the other hand, which have high viscosities in liquid form, produced foams of undesirably high viscosities, even at high foam densities, making them unsuitable for foam application. However, these sizes can be blended with the less viscous polyester

resins and acrylic sizes to produce more suitable products. Cellulose and starch derivatives can also be foamed for use as sizes, but a relatively large amount of foaming agent is required as a result of the defoamers present in these sizes⁹⁴.

4.5 APPLICATION SYSTEMS

In the sizing operation, the foam size must be applied to the warp sheet and subjected to some form of mechanical action to collapse the foam and distribute the size liquor uniformly onto the yarns, followed by diffusion of the liquor into the yarns to the desired level of penetration. The application of the size must be uniform across the width of the warp sheet¹⁰³. The add-on or wet pick-up depends on a number of factors such as foam density, volume of foam applied, mass of the yarn, thickness of foam layer and the production speed¹⁷².

At present there are several foam application techniques available for applying foamed chemicals to textile substrates¹⁷⁰. Although these techniques are mainly used for the treatment of woven fabrics, some techniques, such as the knife-over-roller coating and the pad box systems, have also been adopted for foam sizing¹⁰¹.

4.5.1 Knife-over-Roller Coating System

This method⁹⁴ entails depositing the foam onto one side of the warp sheet and using a doctor knife or doctor roller to regulate the thickness of the foam layer. A foam bank is built up at the knife which is positioned directly over a roller or table (Fig 14). The warp is threaded under the knife and the coating

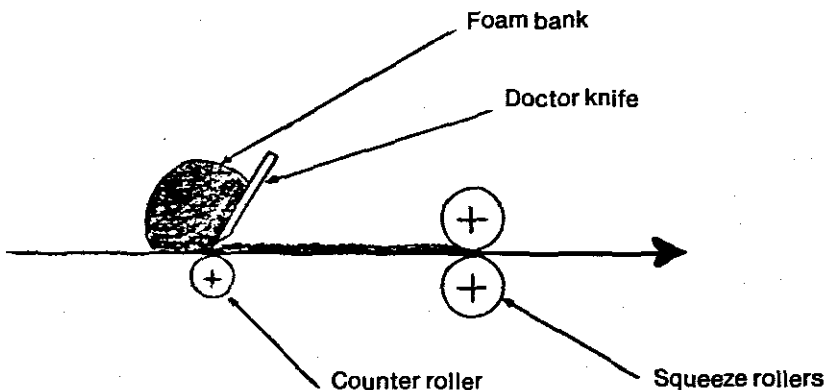


Fig. 14 — Knife over roll system.

thickness is then determined by adjustment of the doctor knife. The warp then passes through squeeze rollers to collapse the relatively stable foam. The foam can also be collapsed by means of vacuum. The amount of add-on of size is determined by the volume of foam metered onto the warp and the setting of the doctor knife, the foam density and the concentration of the original unfoamed size solution⁹⁴.

Research work conducted (on a laboratory scale) at Auburn University^{94,103,113} showed that satisfactory coverage of the yarn was achieved due to the movement of the foam bubbles around the yarn, even though the foam was applied to only one side of the warp sheet. In this case a 50/50 polyester/cotton yarn (27 tex singles) was foam sized with a blend of an acrylic size and a 90/10 acrylic/PVA mixture. The size liquors were foamed to a density of 0,29 g/cm³, but in some cases a foam density as low as 0,04 g/cm³ was used. These foams gave wet pick-ups as low as 20% to 40% when a foam density of 0,08 g/cm³ was used. As far as the yarn properties were concerned, the strength of the foam-sized yarn (6,5% add-on) increased by about 44% against the 33% of the conventionally sized yarn with a 16,2% add-on. No difference between the two systems in terms of yarn elongation could be found, but abrasion resistance of the foam-sized yarn appeared to be as good or better than that of the conventionally sized yarns.

In general, it was found that acrylic sizes did not perform well, while good weavability was obtained when the acrylic size was blended with PVA. Some problems such as bonding of adjacent yarns were experienced. On the other hand foam-sized yarns appeared to be much smoother with a more uniform distribution of size than the conventional sized yarns⁹⁴. The coverage of the yarns by the size was at an optimum with the space between the yarns equal to the yarn diameter. The knife-over-roller coating system showed some deficiency, however, in that the squeeze rollers had a tendency to become dry, causing the size to stick and accumulate. Furthermore, the yarns tended to stick to the drying rollers which plucked the yarn surface fibres resulting in excessive hairiness. This caused clinging and fuzz-ball formation during weaving⁹⁴.

There are some modified versions of the knife-over-roller foam application systems. For example, foam can be doctored onto the roller and then transferred to the warp sheet, similar to a transfer roller system. In the case of the reverse roller coater the doctor roller rotates in the opposite direction to that of the warp sheet.

4.5.2 Horizontal Padding System

This method^{94,103,158,169} requires a set of rubber covered horizontal rollers with end-dam modification (Fig 15). The foamed size is then pumped into the trough created by the pad nip. The warp sheet is threaded vertically through

the foam into the centre of the nip. The system, therefore, can apply the size uniformly to both sides of the warp sheet. As the warp passes through the nip, mechanical crushing causes the foam to collapse and the size to penetrate the yarn.

Size add-on is determined by the concentration of the unfoamed size solution, the foam density and the nip pressure¹⁵². In this particular system foam stability is important in that an unstable foam will form an excessive amount of liquor in the nip, resulting in an uneven application, whereas an excessively stable foam will tend not to collapse in the nip¹⁷³.

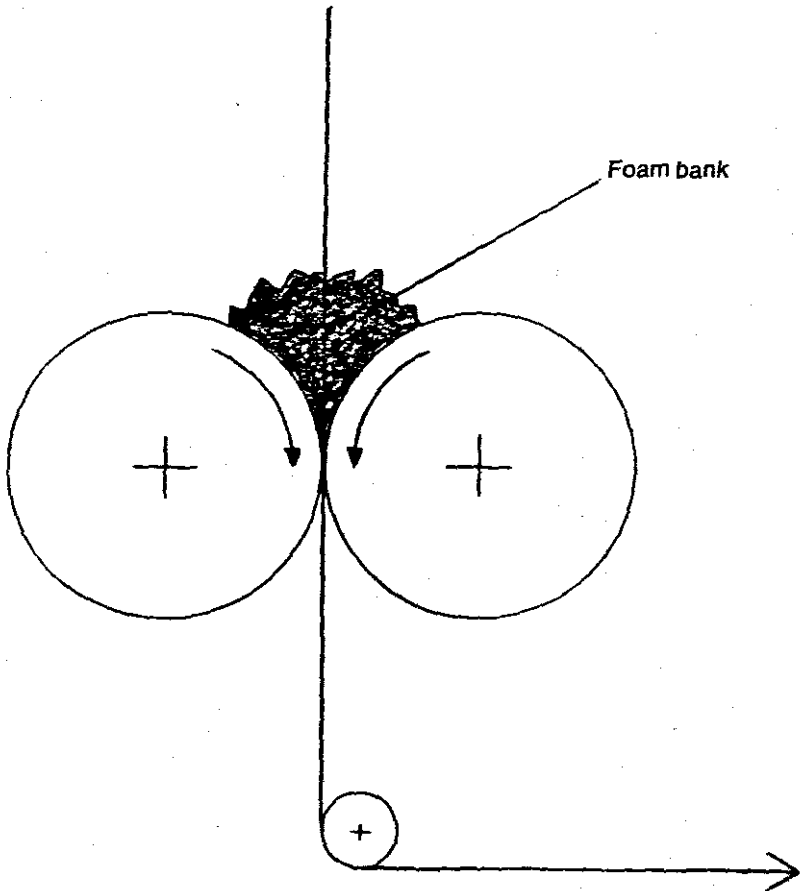


Fig 15 — Horizontal pad system

The padding system has been successfully demonstrated at Auburn University⁹⁴, applying the foam to only one side of the pad from a slotted tube onto the roller. The roller carries the foam into the nip, where a portion of the foam passes between the yarns forming a foam bank on both sides of the yarn. The entire yarn surface thus becomes coated. A soft squeeze at the nip gave best results for spun yarn. Experiments with auxiliary squeeze rollers caused excessive hairiness, as previously experienced in the knife coating method.

The padding system performed best when a 50/50 polyester/cotton yarn (27 tex) was foam-sized at a foam density of 0,13 g/cm³ or lower. Experiments were conducted using foam densities as low as 0,04 g/cm³, giving wet pick-ups as low as 20% with good uniformity of application. Wet pick-ups of 40% could generally be achieved using a foam with a foam density of about 0,08 g/cm³ made from a formulation containing 30% size solids⁹⁴. Scanning electron micrographs revealed that the surface of the foam-sized yarns appears much smoother, and application of the size seems more uniform than the conventionally sized yarns.

An alternative for the horizontal padding system is a pad trough filled with foam, followed by two pad rollers¹⁷⁴. In this system the trough or box instead of the nip contains the foam. The fabric passes through the foam in the box, followed by squeezing by the pad rollers, which collapses the foam. Some of the Seydel companies^{111,175} employed a foam sizing system based upon the pad-box system. In their trials a double pad-box system was used where the yarn was immersed twice and passed through a double-nip arrangement in each size box. A 65/35 polyester/cotton spun yarn (17 tex) was foam-sized with a size add-on of 12,5% at a wet pick-up of 40% to 100%. In some further trials^{175,176} an adjustable slotted tube was fitted across the pad-box at the point where the immersion roller is normally located. In further trials a modified acrylic polymer was also employed¹⁷⁵.

4.5.3 Slot Applicator System

One of the systems using a direct pressurised foam application technique is the Foam Finishing Technology (FFT) system utilising a slot applicator unit and is manufactured by Gaston County. A limited amount of work has been carried out in the use of such a system for foam sizing¹⁷⁷. Although the FFT system was developed for woven fabrics, it was adapted for foam sizing at SAWTRI. A grid bar was placed directly above the slot across the warp which is guided by reeds at both sides of the slot. In this case the size add-on was determined by the liquor flow to the foam generator and the speed of the yarn.

A cotton yarn (30 tex) was foam-sized at different levels of add-on (2% to 12%) using an acrylic polymer giving wet pick-up values of between 40% and 90%. It was found that foam sizing by means of the slot applicator was indeed feasible, producing a range of add-on levels and wet pick-ups. It was found, however, that the size was not distributed uniformly on the yarns in all cases.

In some instances very little size was deposited between adjacent yarns. This was possibly due to the high viscosity of the size and the high foam stability. In the case of the foam-sized yarns, scanning electron micrographs showed that more size was deposited on the outside of the yarn compared with those sized conventionally¹⁷⁷.

4.6 ADVANTAGES OF FOAM SIZING

Apart from the claims which refer to certain specific foam techniques or machines, there is considerable information available about the advantages of foam sizing in general. The main advantage of the foam sizing process is the reduction in the drying energy cost. For example, it was reported^{26,111,167} that the energy requirements for foam sizing was about 50% to 60% of that of the conventional sizing process. In some cases energy savings of between 35% and 40% were reported¹⁷⁵. Furthermore, it was claimed that, in general, the foam sizing process resulted in reduced water consumption¹⁶⁷, because size removal was easier due to the lower degree of size penetration in the yarn^{103,167}. Recovery of the size is also possible⁹⁶. Certain workers claimed that as a result of the better utilisation of chemicals, chemical consumption could be reduced¹⁰³. More specifically, a reduction in the chemical cost of between 6% and 10% was reported¹⁷⁵. Another advantage of the foam sizing process is eliminating the use of steam for cooking, because the sizes are applied cold^{96,167}. Finally, it was reported that, due to the lower wet pick-up levels employed in foam sizes, wet elongation is lower compared with conventional sizing^{96,103,167}. Consequently, the reduction in warp elastic properties is also lower leading to enhanced performance during weaving.

4.7 SOME LIMITATIONS OF FOAM SIZING

It has been reported that certain sizes, such as PVA, did not perform well in foam sizing as far as foaming ability is concerned, and had to be blended with other sizes¹⁷⁵. The high viscosity of some sizes could reduce foaming ability⁹⁶. It was also reported that some sizes caused the foam generator to overheat⁹⁵, or even burn out¹¹¹. Side-to-side variations in size pick-up over various segments of the warp sheet have been observed¹⁷⁵. One case was reported where acrylic sizes tended to build up on the rollers during sizing and on the loom shuttle during weaving¹¹¹.

Perhaps the greatest limitation of foam sizing is the difficulty in maintaining uniform foam characteristics from the moment of generation to the application of the foam onto the warp sheet. Consequently, the foam is applied to the substrate in an inhomogeneous condition leading to uneven application of the size.

CHAPTER 5

SUMMARY

Some recent developments in sizing have been reviewed, namely high-pressure, hot melt and foam sizing.

High-pressure sizing has been shown to significantly reduce wet pick-up and subsequently offer a considerable saving in drying energy costs. This system is currently in production use and would seem to be establishing itself in the industry. Although reference has been made to roller covering fatigue problems, this would seem likely to be overcome by modern plastic and rubber technology.

The hot melt system has adopted a non-aqueous approach to sizing. The size pick-up is determined by the quantity of size adsorbed by the yarns during their rapid passage through the roller grooves. The major limitations are the time required to solidify the hot melt size and the quality of the yarn. The overall production speed is reduced by the need to re-beam.

Foam sizing, on the other hand, is in a much earlier stage of development. The main problems associated with this approach would appear to be the development of size formulations which are compatible with current foam generating systems, or the modification of existing machinery to utilise existing size formulations. Furthermore, the development of application systems to apply the foam in a uniform, consistent manner to the warp is required.

Regarding future developments, the trend will certainly be a reduction in the energy consumed during the sizing process and this will ultimately necessitate reducing wet pick-up. The savings in energy achieved, however, must not be off-set by high capital cost of the system employed. Indeed, if a system can be offered that can utilise a substantial amount of conventional sizing machinery it would certainly be attractive to the industry.

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