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Development Of Mathematical Model To Select Best Technological Parameters In Sizing

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***Abstract*—The sizing process does not add value to the grey fabric, but it is critical to the improvement of weaving efficiency especially for cotton and cotton blend fabrics. With the advent of technology, weaving speeds have been greatly ameliorated and the significance of correct size applications has been thoroughly explored. Since the correct size application is primarily characterized by the size percentage, the technological parameters for proper sizing were chosen through experimental trials and acquired prior knowledge. Thus, a scientific approach to determining the technological parameters is essential to the textile industry. To fulfill the aforementioned need, the authors have developed a mathematical relationship that relates technological parameters involved in size applications. The practical utility of the derived equations were also highlighted. Experimental trials, carried out with poly/cotton yarn on a single yarn sizing machine, confirm the validity of the model developed. Furthermore, empirical findings published in internationally renowned reference books on sizing were also in accordance with the analytical results established. The mathematical relationships developed can be exploited to calculate the optimum parameters of the sizing machine and to obtain the required quality of sized yarn.This approach does not require carrying out costly trials and therefore has positive industrial impacts.**

Keywords—Mathematical model, material waste, size box, Technological parameters of sizing

1 INTRODUCTION

The warp yarns are subjected to internal and external mechanical influences during the weaving process. The warp tension and cyclic tension variations in the warp yarn fall under internal influences while the yarn abrasion at the heald eyes, reed dents, shuttle, and adjacent warp ends, are categorized under the external or surface influences [10]. As the surface influences are further enhanced due to hairiness of the yarn, the warp ends should be essentially preprocessed to mitigate the above undesirable influences. Sizing is such a pre -process to weaving and it has been practiced for more than 5000 years. The sizing was assumed to be practiced from the inception of weaving and it achieved its sophistications in ages. However, the sizing process still remains as an indispensable to date specially in the case of staple yarns.

In sizing machines, the yarn is subjected to various characteristic changes due to the pressure, stretch, heat, wet treatments and to the chemical and physical action of different substances, depending on the yarn count, warp density, fibre type, fabric construction etc.

The size solution applied to the yarn forms a film upon drying and tends to bind the individual fibres together to improve the strength and reduce the yarn hairiness which enhance weavability [5].The objective of sizing is to impart desirable physical and mechanical properties to yarn necessary for weaving with a minimum breakage rate [15]. So, the proper sizing is a key to weaving efficiency and it encompasses the selection of suitable materials, manufacturing conditions for size preparation, physical and chemical treatments carried out on the sizing machine.

Further, in the sizing process, yarns are subject to wet size application and thereby adhere size onto the yarn by drying and cooling.

A number of different yarn sizing methods are currently in use and some of them can be stated as immersion of the warp in size and spray application of size. The size is applied to the yarn in one of the following foams: namely, an aqueous, non-aqueous, wax (as a melt in a solid state) or in a colloidal state (emulsion, suspension, and aerosol) [2]. Among the available methods, the popular method in practice is sizing with aqueous solutions as it can acquire required viscosity, polymer content and good contact between the size and the exterior and interior surfaces of the yarn.

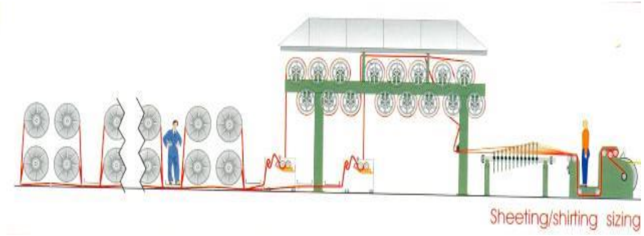

Fig. 1. *Sketch of a sizing machine [IRAL.GRIFFIN SONS,INC.Sizing Systems]*

Figure 1 shows a sketch of a modern sizing machine and it consists of the following parts: a creel for warping beams, a size box, drying cylinders, and headstock. The warp yarns from back beams are drawn forward to produce a continuous sheet of yarns and it is then passed into the size box, which contains the hot sizing mixture. The sized yarn is dried when it runs over large drying cylinders.

During the process, care must be taken to keep all the warp yarns separately, and two warp ends should not be allowed to join together by size. Rods are used to split the yarns, and they are then passed through a reed with spaced wires in the splitting zone and finally sized warp yarns are wound onto a weaver's beam.

The process of size application in the sizing machine is characterized by different zones: namely the unwinding zone, sizing zone, drying zone, splitting zone and winding zone [10] and they are illustrated in Fig.2. Two units corresponding to the zones under the purview of this paper are briefly described for the benefit of the novice reader of this article

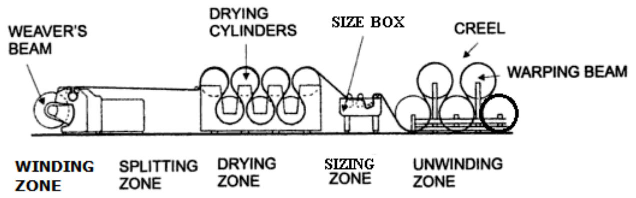

Fig. 2. *Different zones of a sizing machine*

Size Unit: The modern sizing machines are equipped with an automatic size level control device to maintain a constant level of size solution in the size box throughout the sizing operation. The sizing unit is comprised of a size box to maintain a constant level of size solution, concentration and viscosity to ensure a good sizing process, an immersion roller to impregnate warp yarns with size and pair of squeeze rollers to squeeze out the excess size applied and to ensure the formation of a uniform size film around the yarn as illustrated in Fig.3. Uniform temperature of the size solution in the size box is of prime importance as it greatly affects the viscosity of size solution [3]

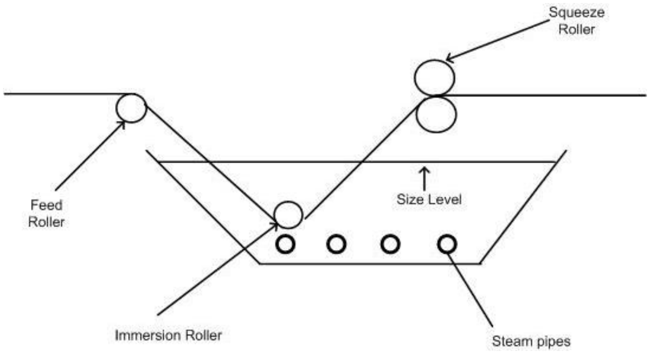

Fig. 3. *Sketch of a size box*

Drying unit: The role of the yarn drying is to vaporize excessive water and to obtain the required moisture regain depending on the type of yarns under processing. Drying of sized yarn to the required level is of great importance for the quality of the warp, the production capacity of the machine and also for the technical and economical viability of the machine.

A. Impact of sizing process on weaving performance

Selecting appropriate sizing materials, size cooking and application of size to warp yarns are the key steps involved in the sizing process. The methodical following up of the above three steps distinctly determines the quality of sized yarns. The quality of the sized yarn is critically dependent on the quantity of the size to be added to the yarn. Among the methods of determining the size coat, quantum method proved to be more accurate [14]. Deviation from the best amount of sizing causes an increase in warp breakages during weaving due to impaired strength cause by under sizing, accumulation of natural slubs, or increased rigidity caused by over sizing.

Penavaet al. emphasized the impact of the sizing on physio-mechanical properties of yarn, and the importance of having optimum size percentage to achieve continuous weaving production and to improve the quality of grey fabric [9]. Additionally, the authors highlighted the significance and complexity towards the standardization of sizing process.

Stana Kovačević et.al carried out an experimental analysis based on the data obtained from a laboratory sizing machine. The authors attempt to establish a correlation among physical parameters of warp yarn with size percentage by varying squeeze roller pressure and size recipe [12]. It is reported that the temperature in the size box, moisture regain, constant size concentration in the size box, as well as automatic regulation of squeeze roller pressure and sizing speed are vital to achieve constant size percentage [7].

Pleva et.al investigated the parameters that are critical for economical and highest-quality production of fabrics through a series of experiments . It was found that size percentage is closely linked with the rate of warp breakages in weaving. Researchers showed the breaking force of all yarns proportionally linearly [6] increases with the size percentage. However, this finding has no practical significance in weaving as the stretchability of the warp yarns are neglected in this research. With the increase of the size percentage (size add-on), stretchability is greatly reduced and more breakages will result in shed formation in weaving. This experimental phenomenon was in accordance with the theoretical explanation provided [2] as shown in Fig.4. A number of supportive evidences could be found on the internet in favour of the same.

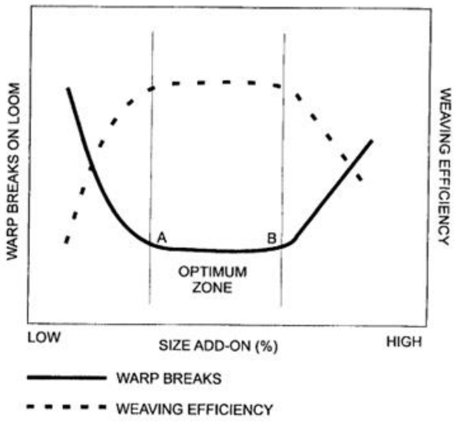

Fig. 4. *warp breakages/weaving efficiency vs. size add-on*

The research work [1,8] confirms that there is no significant difference in the properties of sized yarns in case of pre-wet and standard sizing. However, researchers suggested the further investigation of the standard and other methods of sizing processes to make the sizing application more cost effective by optimizing the sizing materials, water usage and energy consumption.

NejibSejri et. al disclosed the fact that a pre-wetting treatment of warp yarns can reduce the yarn hairiness while reducing the size consumption by 15%–16% . The wet treatment prior to sizing should yield less breakage during weaving [13]. Although this finding is beneficial, the authors failed to establish an empirical relationship among various sizing parameters. It was quite interesting to note that there were virtually no research articles published in the plethora of literature relating to the development of a quantitative relationship mathematically, and this necessitates the development of a mathematical model.

B. Parameters of sizing

The distribution and penetration of size into the yarn are influenced by both physical properties such as fibre count, shape, structure, surface characteristics and induced yarn characteristics such as count, twist level, crimp level, regularity of count and twist [4]. Consequently, these yarn properties affect the size percentage. Evidently not only yarn properties, but also many other parameters related to the sizing process can impact the size percentage.

The moisture regain of unsized yarn and sized yarn is more or less the same and any variations in moisture regain before sizing will lead to a variation in size take up. Any variation of moisture regain in sized from the standard required value would be due to either over drying or under drying in the drying chamber.

The thickness of the size coating on the yarn and inter-fibre penetrability of size particles depend on the size concentration and the bath viscosity. The viscosity of the size solution greatly affects the amount of size solution taken up by yarn, namely wet pick-up, and the amount of size squeezed out by the squeeze rollers.

The depth of immersion is defined as how far the immersion roller sinks into the sizing solution, and any change in depth changes the length of yarn path within the size solution. Thus for a given speed, the modification of the yarn path changes the duration of size impregnation, namely the diffusivity of size particles into the fibre bundle. The duration of size impregnation can also be altered by varying the machine speed. At higher speeds, less time is available for the size solution to cascade down to the size box and less time to squeeze out the excess material [5]. In modern sizing machines, the size level and the temperature in the size box are automatically regulated and the depth of immersion and sizing speed become two vital parameters that determine the amount of size taken up by the yarn.

The squeeze rollers squeeze out the excess size from the wet warp ends ensuring the desired size pick up and facilitating the size penetration into the yarn. The amount of squeeze and the penetration depend on squeeze roller hardness, thickness of roller covering, and pressure applied at the squeezing nip. As a result, the size pick up by the warp varies from place to place within the same beam [5].

Warp stretch is another important parameter to be considered in the sizing process. Though stretching can induce strength by an additional 15 -20%, the yarn stretchability is reduced due to the application of size into the yarn. The reduction in the yarn’s stretchebility in sizing tends to increase warp breakages during weaving as warp ends are subjected to elongation during shedding and beat up actions. This reduces the production efficiency and is undesirable.

II. MATHEMATICAL MODEL OF SIZE APPLICATION

Since slight variation could be noted in the technical jargon found in the literature, the authors intend to state the related definitions used in this article. Size percentage is a key parameter which determines the quality of sizing process. It is a quantitative parameter which characterizes the amount of size penetration and deposition on yarn. In more precise terms, size percentage is the mass of oven-dried size applied on a unit weight of oven-dried unsized yarn and is customarily expressed as a percentage. Size percentage, S%, can be mathematically expressed as [11,12]

$$S = \frac{M_{DS}}{M_{UY}}.100\% \qquad (1)$$

Where $\mathrm{M_{DS}}$ and$\mathrm{M_{UY}}$ are the mass of oven-dried size in the yarn and the mass of oven-dried unsized yarn respectively.

It is important to maintain size percentage at a constant level under given factory conditions and even a small deviation from the optimum level can greatly influence the weaving process. The optimal size percentage greatly depends on yarn count, type of fibres, and twist level of the yarn.

The size concentration is defined as the percentage mass of oven-dried solid size to mass of the size solution. This is also kept constant in modern sizing machines throughout the process of sizing. The size concentration C%, can be expressed as

$$C = \frac{M_S}{M_{SP}}.100\% \qquad (2)$$

Where $\mathrm{M_S}$ and $\mathrm{M_{SP}}$ are mass of oven-dried size in the size solution and mass of the size solution.

The size take up, T%, can be expressed as the percentage of mass of size solution taken up in the size box to unit mass of oven-dried unsized yarn.

$$\mathrm{T} = \frac{\mathrm{M_{ST}}}{\mathrm{M_{UY}}}.100\% \tag{3}$$

Where $\mathrm{M_{ST}}$ is the mass of size solution taken up in the size box.

The size pick up, P%, is defined as the percentage of mass of size solution remaining in the yarn after squeezing by rollers to unit mass of oven-dried unsized yarn and can be given as

$$\mathrm{P} = \frac{\mathrm{M_{SS}}}{\mathrm{M_{UY}}}.100\% \tag{4}$$

Where $\mathrm{M_{SS}}$ is the mass of size solution remaining in the yarn after squeeze rollers.

Moisture regain M% is defined as the percentage of mass of moisture in oven-dried yarn to unit mass of oven-dried unsized yarn.

$$\mathrm{M} = \frac{\mathrm{M_M}}{\mathrm{M_{UY}}}.100\% \tag{5}$$

Where $\mathrm{M_M}$ is the mass of moisture in oven-dried yarn. When calculating moisture regains before and after sizing, the mass of moisture in oven-dried unsized yarn and sized yarn are respectively taken into consideration.

Warp stretch, $\mathrm{E_W}$%, in sizing can be expressed as the percentage elongation of the warp yarn for a unit initial length of the warp yarn and it could be mathematically expressed as

$$E_W = \frac{\mathrm{L_S}}{\mathrm{L_W}}.100\% \tag{6}$$

Where $\mathrm{L_S}$ and $\mathrm{L_W}$ are the warp yarn elongated from its initial length and the initial length of the warp yarn respectively.

Figure 5 illustrates a detailed technical diagram of a size box with technological parameters. Size is circulated automatically in modern size boxes and therefore the size level in the size box, y, temperature in the size box, θ, size concentration, C, and viscosity ξ, are assumed to be constant. In the development of the mathematical model, mass of yarn (in grams) in different sections along the yarn path in time (t0 in seconds) is considered.

The mass of yarn before the feeding roller composed of the mass of the oven-dried unsized yarn $\mathrm{M_{UY}}$and the mass of moisture in the same $\mathrm{M_B}$. When the unsized yarn passes through the size box, a mass of size solution $\mathrm{M_{ST}}$ is applied onto the same yarn length within a duration t. Subsequently, the yarn is subjected to squeezing under a pressing force, Q, (usually referred to as the squeeze roller pressure) which impregnates size into the yarn, removes excessive size solution and forms a uniform size film around it. After squeezing, the mass of size solution, $\mathrm{M_{SS}}$, remains in the yarn is then dried in the drying chamber so that the total mass $\mathrm{M_A}$ of moisture is remained in the dried sized yarn.

The solid mass of the size retained with the yarn output during time t is equal to $\mathrm{M_{DS}}$ and output delivery speed is increased to $\mathrm{v_{S1}}$ from the input speed of $\mathrm{v_S}$ (where Vs1 is about 10~15% faster than Vs).

The sizing process is one of the wet processes in which yarn is subjected to elongation and hence it is essential to regulate the delivery speed of the size yarn to keep the tension of sized yarn constant. The process described above can be expressed by the following set of dynamic equations.

$$\frac{dM_{ST}}{dt} = \frac{M_{UY}\,T}{100t_0} \tag{7}$$

$$\frac{dM_{SS}}{dt} = \frac{M_{UY}\,P}{100t_0} \tag{8}$$

From equation (2) C can be expressed as follows

$$C = \frac{M_{DS}}{M_{SS}}.100 \tag{9}$$

With the above described conditions, the total mass of water evaporated in the drying chamber/unit time can then be expressed as:

$$\frac{M_{SS}+M_B-M_A-M_{DS}}{t_0} = \frac{D*10}{36} \tag{10}$$

Where D is the drying capacity of the chamber and it is usually expressed in kg/ hour

If the length of the unstressed yarn of mass $(\mathrm{M_{UY}} + \mathrm{M_B})$ is assumed to be $\mathrm{L_W}$ then,

$$L_W = \frac{1000}{T_{tex}}.M_{UY} \tag{11}$$

$$V_S = \frac{L_W}{t_0} \tag{12}$$

$$V_{S1} = \frac{L_1}{t_0} \tag{13}$$

From equation (6)

$$E_W = \frac{\mathrm{L_1}-\mathrm{L_W}}{\mathrm{L_W}}.100 \tag{14}$$

Where D is the drying capacity of the chamber

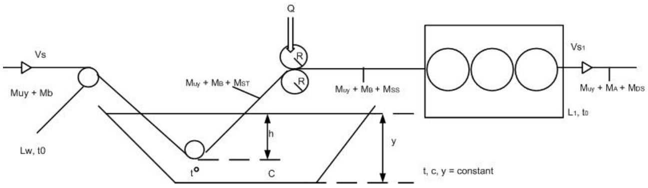

Fig. 5. *Detailed sketch of the size box*

If substitute from equation (12) and (13), (14) yields:

$$E_W = \frac{\mathrm{V_{S1}}-\mathrm{V_S}}{\mathrm{V_S}}.100 \tag{15}$$

Solving equations (10), (9), and (1) yields

$$3.6\left(\frac{100}{c}-1\right)\frac{s}{t_0} + 3.6\left(\frac{M_B-M_A}{t_0.M_{UY}}\right) = \frac{D}{M_{UY}} \tag{16}$$

If equation (10) is solved by substituting from equations (9) and (4), the following equation can be derived.

$$3.6\left(1-\frac{c}{100}\right)\frac{P}{100.t_0} + 3.6\left(\frac{M_B-M_A}{t_0M_{UY}}\right) = \frac{D}{M_{UY}} \tag{17}$$

The amount of size take-up (commonly known as wet-pick up or wet add-on) by the yarn proportionately increases with the surface area of the immersed yarn in the size solution but nonlinearly with the feeding speed.

$$\mathrm{M_{ST}} = 2\pi\mathrm{d}.k_1\sqrt{(\mathrm{a}^2+\mathrm{h}^2)}.f_1(\mathrm{V_s}) \qquad (18)$$

Where a is the horizontal distance between the entering point of yarn into the size solution and the vertical plane passes through the axis of immersion roller, d is the average yarn diameter, h is the vertical height from the liquid surface to the lowest point of the immersion roller, $\mathrm{f_1}$ is a non-linear function of sizing speed, and $\mathrm{k_1}$ is the proportionality constant. For a given type of yarn, $\mathrm{k_1}$depends on its physical characteristics such as type, count, compactness, and so on.

The mass $(\mathrm{M_{SS}})$ of wet size impregnated and encapsulated yarn is inversely proportional to the real time nip roller pressure and non-linearly increases with the sizing speed.

$$\mathrm{M_{SS}} = k_2\frac{Q}{\alpha R}.f_2(\mathrm{V_s}) \qquad (19)$$

Where α is the angle of contact of the rubber coated nip roller and the incoming yarn, R is the radius of the rubber coated squeeze roller, $\mathrm{f_2}$ is a non-linear function of sizing speed and $\mathrm{k_2}$ is a constant of proportionality for a given type of yarn. $\mathrm{K_2}$ depends on the surface properties of the rubber coated squeeze roller.

III. RESULTS

A. Experimental setup

Fig. 6. *Single yarn sizing machine*

The experiment was carried out under laboratory conditions on a single yarn sizing machine (KHS Universal Sizer). Figure 6 shows a picture of the sizing machine and its specifications are given below.

Make: KHS Universal Sizer produced by Kakinoki SeisakaSho. Co. Ltd

Sizing speed range: 200m/min~400 m/min
Squeeze roller pressure range: 5kg to 27.5kg

The experiment was carried out on polyester/cotton: 65/35 yarn of count 20s and 45s. During the experiment, the temperature of the size box was maintained within the range of 500-600C and size solution was prepared with PVA and starch as main adhesives according to the standard size recipe. The weight of the yarn samples were measured with a German made precision electronic balance (Model KERN /ABJ220-4m) with a minimum resolution of 0.0001g.

TABLE 1: YARN WEIGHT WITH SIZE TAKE UP BEFORE SQUEEZE ROLLERS AT DIFFERENT SIZING SPEEDS AND DIFFERENT DEPTH OF IMMERSION ROLLER

Sizing Speed	**Depth of the immersion roller**	**Average yarn weight after the size box [s.d.] in grams**	
		Poly/cott 45^s (weight of unsized yarn 0.0177g)	***Poly/cott 20^s (weight of unsized yarn 0.0401g)***
200 m/min	Top	0.0260 [0.0028]	0.0922 [0.0101]
250 m/min		0.0341 [0.0032]	0.0973 [0.0082]
300 m/min		0.0378 [0.0044]	0.1020 [0.0112]
350 m/min		0.0390 [0.0033]	0.1043 [0.0105]
200 m/min	Middle	0.0325 [0.0023]	0.0940 [0.0075]
250 m/min		0.0376 [0.0042]	0.1004 [0.0093]
300 m/min		0.0440 [0.0034]	0.1045 [0.0090]
350 m/min		0.0456 [0.0035]	0.1090 [0.0091]
200 m/min	Bottom	0.0397 [0.0045]	0.0985 [0.0098]
250 m/min		0.0446 [0.0044]	0.1043 [0.0096]
300 m/min		0.0486 [0.0037]	0.1100 [0.0129]
350 m/min		0.0490 [0.0039]	0.1134 [0.0094]

B. Experimental Results

The experiment was mainly focused on polyester/cotton 65/35 yarn of count 20s and 45s.The predetermined yarn lengths that were coming out of the size box were collected and their weights were measured using an electronic balance at different sizing speeds (200, 250, 300 and 350 m/min) while varying the immersion roller heights at three different levels (namely the top, middle, and bottom). This procedure was repeated to collect 25-30 samples at each sizing speed while maintaining a constant size concentration, viscosity, temperature, immersion roller depth, and size level. The average weight and the standard deviation were calculated and are tabulated in Table 1.

The second stage of the experiment was quite similar to the first except that the yarn was weighed after it passed through the squeeze rollers (with size pick up) at varying pressures. The squeeze roller pressures were set to 5kg, 12.5kg, 20.0kg, and 27.5kg while the sizing speeds were set to 200,250,300, and 350 m/min. The immersion roller was kept at the bottom and middle positions of the size box like in the first stage of the experiment. Thirty observations were taken for every set of different parameters and the averages as well as the standard deviation of sized yarn weights were calculated. The calculated values are tabulated in Table 2.

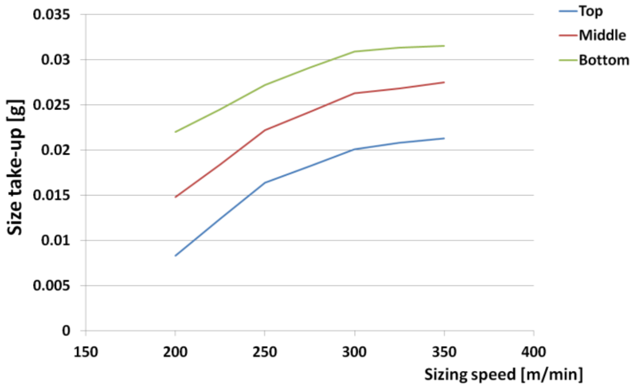

Fig. 7. *Size take-up vs. sizing speed for yarn count 45S at different depth of immersion roller*

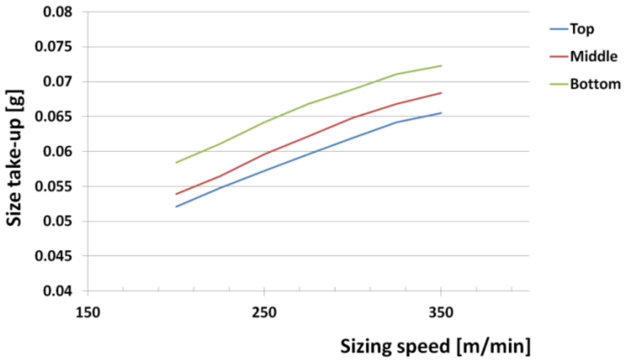

Fig. 8. *Size take-up vs. sizing speed for yarn count 20S at different depth of immersion roller*

TABLE 2: VARIATION IN YARN WEIGHT WITH SIZE PICK UP AT DIFFERENT SIZING SPEEDS, DIFFERENT SQUEEZE ROLLER PRESSURE AND DIFFERENT IMMERSION ROLLER DEPTHS

Squeeze roller pressure	Depth of the immersion roller	Sizing Speed	Average yarn weight after the size box [s.d.] in g		Average yarn weight after the squeeze rollers [s.d.] in g	
			Poly/cott 45s	*Poly/cott 20s*	*Poly/cott 45s*	*Poly/cott 20s*
5.0kg	Bottom	200	0.0397 [0.0045]	0.0985 [0.0098]	0.0340 [0.0046]	0.9450 [0.0962]
12.5kg					0.0290 [0.0029]	0.0592 [0.0063]
20.0kg					0.0240 [0.0033]	0.0525 [0.0071]
27.5kb					0.0201 [0.0024]	0.0490 [0.0059]
5.0kg	Bottom	300	0.0486 [0.0045]	0.1100 [0.0129]	0.0398 [0.0036]	0.0880 [0.0089]
12.5kg					0.0234 [0.0024]	0.0519 [0.0055]
20.0kg					0.0225 [0.0026]	0.0473 [0.0059]
27.5kb					0.0232 [0.0021]	0.0485 [0.0064]
5.0kg	middle	200	0.0325 [0.0023]	0.0940 [0.0075]	0.0270 [0.0036]	0.0802 [0.0108]
12.5kg					0.0225 [0.0021]	0.0457 [0.0050]
20.0kg					0.0201 [0.0022]	0.0425 [0.0044]
27.5kb					0.0190 [0.0024]	0.0421 [0.0051]
5.0kg	middle	250	0.0376 [0.0042]	0.1004 [0.0093]	0.0294 [0.0034]	0.0852 [0.0091]
12.5kg					0.0230 [0.0025]	0.0476 [0.0058]
20.0kg					0.0215 [0.0029]	0.0449 [0.0060]
27.5kb					0.0211 [0.0026]	0.0430 [0.0052]
5.0kg	middle	300	0.0440 [0.0034]	0.1045 [0.0090]	0.0363 [0.0038]	0.0901 [0.0084]
12.5kg					0.0297 [0.0039]	0.0501 [0.0056]
20.0kg					0.0240 [0.0026]	0.0470 [0.0059]
27.5kb					0.0222 [0.0023]	0.0440 [0.0044]
5.0kg	middle	350	0.0456 [0.0035]	0.1090 [0.0091]	0.0390 [0.0052]	0.0922 [0.0088]
12.5kg					0.0305 [0.0039]	0.0517 [0.0068]
20.0kg					0.0250 [0.0026]	0.0460 [0.0044]
27.5kb					0.0235 [0.0026]	0.0448 [0.0054]

Figures 7 and 8 show the size take-up as a function of sizing speed at different immersion roller depths for yarn counts of 45S and 20S respectively. As the sizing speed increases, irrespective of the roller position, the size-take up linearly increases until they finally reach a plateau which is the saturation point. The size take-up with speed also demonstrates the same trend regardless of the roller position. With the increase of the speed, irrespective of the position of the roller, all trials follow the same profile of size take-up and gradually saturate with speed. Within the size speeds ranging from 200-350m/min, the yarn count of 45S shows a clear saturation, while a coarser yarn of count 20S begins to saturate but could not clearly reach the saturation point.

In the industry, it's customary to use sizing speeds of 150-400 m/minute. Considering the practical limitations of the polyester/cotton yarn (at very high speed yarn breaks) and the specifications of the experimental setup, the sizing speeds were chosen to match the industrial requirements. Furthermore, size-take up gradually increases as the depth of immersion roller increases irrespective of the yarn count. It was also noted that the amount of size take-up of yarn with count 20S was higher than that of 45S.

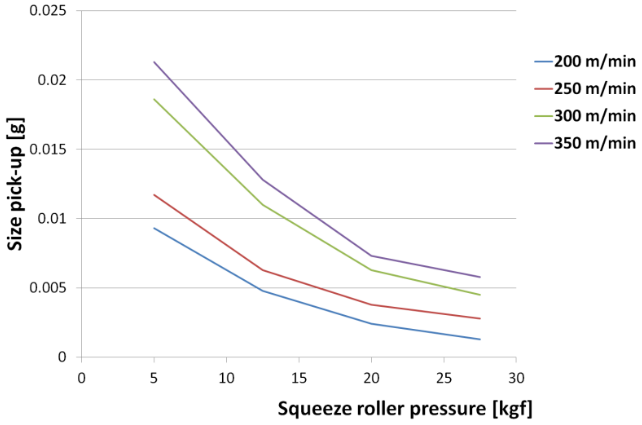

Fig. 9. *Size pick-up vs. squeeze roller pressure for yarn count 45S at different sizing speeds*

Size pick-up against the squeeze roller pressure for yarn counts 45S and 20S at different sizing speeds were shown in Fig. 9 and Fig. 10 respectively. When obtaining the above size pick up, the immersion roller was kept at the middle position of the size box.

For a given sizing speed, the increase in squeeze roller pressure resulted in a significant initial drop followed by a gradual decrease in the size pick-up. This fact was valid for all yarn counts.

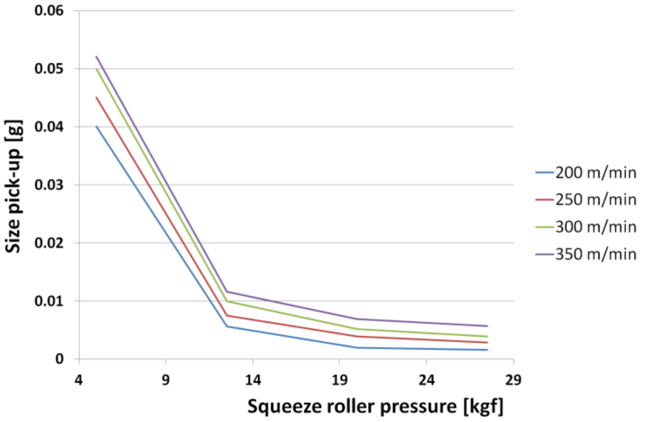

Fig. 10. *Size pick-up vs. squeeze roller pressure for yarn count 20S at different sizing speeds*

However, a significant reduction of size pick-up could be noted for the initial squeeze roller pressures which formed thicker yarns at higher sizing speeds, size pick-up was further improved for all yarn counts.

IV. DISCUSSION

Equations (1) to (6) were used to mathematically express the definition of various technological parameters involved in size application and they are subsequently used to derive other useful equations. Size take up T, as given in equation (7), is proportional to the mass of size take up by the yarn for a given mass of unsized yarn. The same results are acquired for a given time at a particular sizing speed or given length of yarn. During the experiment, size take up was measured for a given length of a particular yarn ata constant size concentration and viscosity. Different readings were obtained at various sizing speeds and various immersion roller depths (refer Table 1). The acquired weight readings represent the measured size take up which can also be calculated from the experimental data as verification. So the percentage of size take up was increased with the increment of sizing speed showing the saturation profiles given in (Fig.7 and Fig.8). The saturation point is somewhat uncertain for thicker yarn. This may be caused by the size build-up at the squeezing point, and/or size tunneling effect especially at faster speeds. Additionally, as the immersion roller depth increased, the impregnation time increased. Consequently, the monitored size take-up percentage also increased.

Similarly, the percentage of size pick up after squeeze rollers were represented by the data given in Table 2. So the behavior of the percentage of size pick up can be observed with the variation of sizing speed, immersion roller depth and squeeze roller pressure. The depth of immersion roller and sizing speed caused an increase in the percentage of size pick up. Conversely, increasing the squeeze roller pressure tends to reduce the percentage of size pick up with an exponential decay for any yarn. These phenomena could be easily identified from Fig. 9 and Fig.10.

Equation (9) provides a pragmatic way of calculating the effective size concentration of size application. However, throughout the experiment, the size concentration and temperature of the size box were automatically regulated and therefore provided no viable calculations to the above equation. Equation (11) provides an important theoretical approach of establishing the relationship between the yarn's Tex count and length. The speed differential between the squeeze roller and winding equipment resulted in a yarn elongation which can be theoretically calculated from equation (15). Thus, it may be very useful in determining the winding speed for a given sizing speed to keep the relative elongation of the yarn below a certain stretch threshold so that the yarn breakage can be mitigated during weaving. To achieve the sizing benefits of stretched yarn, the winding speed was kept 10-15% faster than the squeeze roller speed during the experiment.

For a given sizing speed, namely for a given size solution exposure time, the weight of the unsized yarn onto which size is applied is constant. The moisture regained from the yarn before and after sizing is required to remain constant for more effective weaving. Therefore, equations (16) and (17) represent a set of linear equations in which the intercept and gradient are constant for a given sizing speed and size solution concentration. As the size concentration increases, the gradients of both sets of equations decline and give a set of lines one beneath the other. The empirical set of graphs given in Fig. 4.38 on page 283 of [2], identically matched with the set of equations represented by equation (16). Thus, this fact endorses the validity of theoretical derivation proposed in this article. Equations (16) and (17) are salient in setting the sizing speed and selecting the appropriate size concentration to obtain the required size percentage that provides constant moisture regain.

V. CONCLUSION

The optimal size application to warp yarns is a key requirement for a defect-free, highly efficient weaving process. The size percentage is the decisive parameter which determines the appropriate size application. However, setting technological parameters to achieve the required size percentage through a trial and error adjustment method is supported by prior knowledge. Such an approach is certainly costly since it requires not only maintaining past trial records but also could waste a significant amount of sizing materials, energy, yarns, production down time, machine opportunity, and labour at each trial set up. Certain empirical relationships were instrumental in reducing production waste, and the cost involved. Hence, there is a burning industrial need of a theoretical insight to size application. This niche was explored by the authors through this article.

The mathematical relationship between the technological parameters which govern the size percentage to achieve the primary objective of optimal sizing was established. The industrial utility of the derived equations were also highlighted. Through a series of experiments, the validity of the established mathematical relationship was verified. Furthermore, the empirical relationships found in the well-known and long-accepted literature endorsed the veracity (OR authenticity/ adaptability) of the system of derived equations. The established mathematical relationships have the potential to uniquely determine the technological parameters of sizing such as exact size concentration, sizing speed, squeeze roller pressure, and immersion roller depths and then to achieve the required quality of sized yarn for a given drying chamber capacity. Hence, the revealed findings of this article have strong commercial and practical impacts in the textile industry.

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