# PREPARATION AND WEAVING OF COTTON YARNS WITHOUT THE TRADITIONAL WARP SIZING (SOME NEW CONCEPTS)

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## Abstract

The centuries-old, global traditions of sizing a cotton warp for weaving and then desizing the greige woven fabric for quality bleaching, dyeing and finishing are costly, complex, and now considered environmentally sensitive. This is so, because these two textile manufacturing processes require a lot of expensive energy, water supply, waste water treatment and discharge, and, more importantly, chemical formulations that are complex and not benign to our environment. Thus, obviously for good reasons, the textile industry would like to eliminate, if at all possible, these age-old processes by essentially eliminating the main, underlying process of warp sizing. The scientists at Southern Regional Research Center have been asked to conduct research under a new CRIS to explore sizeless weaving. They have come up with some new ideas and concepts about the sizeless weaving, which is the subject of this paper. The paper basically summarizes the proposed research and has two purposes. One is to disseminate our thinking about the sizeless weaving and the other and perhaps the more important one is to seek an input in the form of any comments or new ideas from the readers, which would assist us in the research project. Although the goal of the proposed research is to develop a wholesome technology involving all aspects of yarn spinning, preparation and weaving, which ultimately would enable weaving on a modern high speed weaving machine a cotton or a predominantly-cotton warp without or with a reduced amount of the traditional size, a special emphasis is on the *yarn setting without the traditional size film* and on the importance of attaining *a consistent tension of individual yarns on the loom beam*.

## Introduction and Research Justification

Cotton's excellent characteristics of (moisture) absorption, transportation, dissipation, and, hence, wear-comfort are still unrivaled by the competing synthetic fibers. However, as we speak, there remains a very stiff competition between the cotton and the synthetic fibers even in the apparel markets where cotton traditionally has been considered the "king of fibers." Unless improved, cost effective, and environment-friendly cotton processes and products continue to be brought to the market place, the competition between the natural and synthetic fibers will intensify and get even stiffer. Therefore, to maintain and expand markets for the American cotton, it is essential for the domestic cotton textile industry to continue to be competitive with the rest of the textile industry which predominantly uses manmade fibers. A systematic research toward development of improved, cost-effective, and environmentally-safe cotton textile processes and products should benefit the American cotton producers, user mills, and consumers.

Sizing of cotton warp yarns for weaving and the subsequent desizing of the greige woven cloth for quality bleaching, dyeing, and any special finishing are the age-old processes. The traditional sizing/slashing involves coating the warp yarns with a strong film of an adhesivesuch as PVA, CMC, starch, etc., along with a number of other chemicals, to assist weaving or weavability of the warp yarns. The fabric desizing involves a complete removal of the size from the woven fabric to achieve satisfactory bleaching, dyeing and finishing. Both the warp sizing and the fabric desizing have long been regarded as critical processes in the manufacture of woven cotton textiles. In fact, the warp sizing is now considered even more critical for today's high-speed shuttle-less weaving which must have lower loom stops to achieve a given efficiency. To give an indication of the critical importance of the traditional sizing and slashing, it may be mentioned that a minute's production of the slasher will typically last an entire 8-hr shift in the weave-room. Therefore, any unsatisfactory condition in the sizing/slashing of the warp can create a havoc not only in the weaving process but also in the fabric dyeing and finishing processes as well. The purpose of sizing basically has always been two-fold:

1) Preparing warps of maximum quality that will weave top efficiency and fabric quality, and
2) Presenting the greige woven cloth to the finishing department for easy, complete, cost-effective, and environmentally-safe removal of the various chemical additives used in the size, which otherwise may interfere with the chemicals used in the subsequent fabric dyeing and finishing treatments. Even traces of certain chemical residues in the desized fabric can sometime create an havoc in the fabric dyeing and finishing. Indeed, the presence of up to 24 different chemical ingredients in a typical size mix or formulation makes the fabric desizing to the finisher as important and critical as the warp sizing is to the weaver. Both the processes considerably influence the

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productivity, quality, and, hence, the overall economics of the fabric manufacturing.

Profitability of a weaving operation mainly depends on the weaving efficiency and the fabric quality, which largely depends on the incidence of loom stoppages. Depending on the loom type, the fabric width and style, the weaving conditions, and the yarn quality and preparation (which includes the winding, warping, especially sizing/slashing, beaming, and knotting, etc.), the loom stoppages due only to the yarn related failures may vary widely, ranging from, say, less than 0.5 to more than 4 per loom hour. Beside proper patrolling in the loom alleys, a good weaver typically can comfortably mend about 30 yarn failures/loom stops per hour, which roughly translates to a work load of handling about 30 weaving machines, assuming that the average loom stops due to yarn failures is about one per machine hour, or approximately 6 per $10^5$ picks and $10^4$ ends. Considering that a loom stoppage on a modern weaving machine today can cost up to $0.50, the cost of weaving can vary from a few cents to more than a dollar a linear yard, which truly makes the weaving operation the most expensive per unit weight production. For given weaving machine and fabric style, the incidence of yarn-related loom stops and hence the weaving efficiency largely depend on the quality of the sized warp, which obviously makes the traditional warp sizing/slashing a very important and critical component having a significant impact on the weaving operation.

As mentioned previously, both the warp sizing and the subsequent *fabric desizing* are complex and costly processes and present a multitude of technical problems. For example, any loss of control in the sizing and/or desizing processes can cause havoc in the weaving and finishing departments, resulting in a significant loss of fabric production and quality. Further, both the operations are costly users of chemicals, energy and water and, above all, are now considered environmentally sensitive. Chemicals used in a typical sizing formulation represent about 80% of the total cost of sizing with the labor, energy, maintenance, etc., collectively representing only 20% of the cost. Since textile mills generally rely on the recommendations given by the size (chemical) producing conglomerates such as DuPont, Air Products, Seydel & Wooley, etc., it is possible that because of the producers' interest in selling the chemicals, the mills may be using more size add-on than they really should. Furthermore, it takes about 45 gallons of water to produce a yard of finished cotton fabric. Most of this water requires an expensive waste water treatment before it can be discharged in to the nation's sewer systems, which may cost thousands and even millions of dollars a year to an average textile mill. According to EPA and other state and local agencies which monitor the waste water controls, the BOD (biological oxygen demand) of some of the discharged water today is still too high. Needless to mention, all the textile wet processes require a lot of energy in the application and drying/curing of various chemicals.

So, mainly because of the economic and environmental concerns about the traditional sizing and desizing operations, the U.S. cotton textile industry has taken an initiative and a step in the right direction to at least explore the possibility of either eliminating the sizing or perhaps substituting it with some sort of permanent sizing with chemicals that, while assisting the yarns through weaving, remain on the fabric (i.e., no desizing) and may, in fact, enhance the fabric performance during its useful life. However, recent developments of new sizing technologies such as hot melt sizing, foam sizing, and solvent sizing have been treated with considerable caution and skepticism by the industry, since none of these technologies has met a great deal of success. The research proposal presented here is an attempt to eliminate or at least minimize the traditional sizing.

## Sizeless Weaving

Although a lot of research has been done and reported on the traditional sizing and on the traditionally sized yarns for weaving [1-105], there is no reference of any work on weaving of sizeless cotton yarns. Obviously, there must be many difficult, if not unresolvable, problems why the sizeless weaving has not been seriously researched. Since the weaving of only sized cotton warps has always been and still continues to be investigated globally and since weaving of sizeless warp yarns has never been comprehensively studied, we frankly do not even fully understand the implications or underlying problems of the "sizeless" weaving. In fact, the failure mechanism of even a traditionally sized warp yarn during weaving has not been well understood and documented, thus far. If we somehow can understand the exact mechanism or cause of yarn breakage during weaving, we probably could use that knowledge to engineer yarns of desired characteristics and manipulate weaving conditions and other parameters accordingly.

This reporter, however, strongly believes *that there are certain acute shortcomings, especially in the yarn spinning and preparation, which could significantly contribute to the yarn failure during weaving but which have not yet been identified or investigated*. Beside the known and/or obvious reasons such as crossed ends, major yarn defects, apparent weak spots, etc., *the yarn winding tension variations generally experienced within a yarn package and among different yarn packages in the spinning, winding, warping, and, more importantly, beaming operations seem to be the prime suspects for the warp yarn failure in weaving*. If we critically examine the yarn spinning process, the various yarn-preparatory processes, and the weaving operation or mechanism, we may conclude the following:

a) The thousands of warp ends (individual yarn strands) assembled on a loom beam had, in fact, been spun, wound, warped and finally beamed *with inconsistent winding tensions and hence stretch levels* over the entire length of the warp (several hundred yards).
b) Depending on the cloth pick density, the cloth take-up (i.e., the linear forward movement or take-up of the cloth <u>and *not necessarily of all the individual yarn strands in the warp sheet*</u>) will be of certain constant magnitude, especially on a modern precision shuttle-less weaving machine.
c) The warp yarn let-off (i.e., the linear forward movement or delivery of the "entire warp sheet") is not of constant magnitude, *since it is controlled by a spring-loaded back-rest which essentially senses only the "overall average tension of the entire warp sheet" and does not at all detect and/or control "the tension or stretch levels of the individual yarns comprising the warp sheet on the loom*. As previously mentioned, the warp sheet on the loom is comprised of several thousand yarn strands, each of which was spun, wound, warped and beamed with varying tensions and hence stretch levels (of course, within a certain range).
d) Since the warp let-off and hence the warp delivery is influenced by the "overall pressure or tension" of the entire warp sheet on the spring-loaded back-rest (whip-roll), some of the individual yarns (in the warp sheet) which had been "*wound*" (onto the loom beam) with a relatively *"greater-than-average tension or stretch" will progressively get stretched and tighter with each pick of the cloth take-up. This is so, because the relatively more tightly wound yarns in the warp sheet will still have to "keep up" (in their forward movement) with the rest bulk of yarns (of normal/average tension/stretch level) which largely determine and consequently control the yarn delivery from the beam, while the cloth take-up and forward movement remains consistent and constant*. Obviously, a progressively strained yarn, which can not withstand its accumulated stress during its passage from the beam to the fell of the cloth, will fail and stop the loom. If such a strained yarn also happens to have any "weak region" at some point along its length, it would be even more likely to break because of its relatively lower endurance threshold.

Thus, the above arguments suggest that the yarn tension/stretch variations within a yarn and among different yarns on the loom beam may indeed be one of the major factors, if not the "hidden" factor, which may indeed be ultimately responsible for causing the yarn failure during weaving. Unfortunately, this factor has never been identified nor has ever been promoted for investigation. On the other hand, it is possible that some of the proclaimed attributes of the traditional sizing actually may not be true and that some of the misconceptions (anticipated problems) about the sizeless weaving may prove to be false, instead. For example, it is quite possible that the "stiff" projecting fibers (yarn hairiness) of a traditionally sized yarn may actually cause an even more severe (stronger) fiber-to-fiber clinging in weaving than what the "soft and flexible" hairs of an appropriately lubricated sizeless yarn probably would. In other words, it is conceivable that a sizeless cotton yarn may, in fact, have a less tendency of severe yarn-to-yarn clinging and, hence, may not be as detrimental in weaving as we presently might suspect based on our illconceived perceptions about sizeless weaving and on our experience with the "sized" and "undersized" warps only. Similarly, the relatively higher tensile extensibility and breaking elongation of a sizeless cotton yarn may actually prove to be much more favorable in weaving than what may be anticipated, since these particular yarn attributes are critical for good weaving. It may be noted that a traditionally sized yarn generally has much lower extensibility and breaking elongation. Another and yet potentially encouraging note in favor of the sizeless weaving is that the overall quality of cotton and cotton yarns worldwide has improved considerably in the last two decades or so and that during the same time period there have been phenomenal developments and improvements in the spinning and weaving machinery -- all of which possibly could have a significant positive impact on the proposed weaving of cotton warps without the traditional sizing.

## <u>Research Approach</u>

The first step in solving any problem really is to understand and define the problem and the best approach to understand the problem is to audit/analyze the data. Since we could not find any data or information on weaving of sizeless (singles) cotton yarns on commercial machines, we might as well first try to briefly discuss the theoretical or suspected potential problems and concerns of the "sizeless weaving." *Basically, the traditional warp sizing stabilizes the yarn twist liveliness or torque and improves the yarn abrasion resistance, surface smoothness and texture (thereby, reducing the yarn-to-yarn and/or fiber-to-fiber clinging), tensile breaking strength, and impact resistance - all of which are known, or at least proclaimed, to ultimately assist weaving. As noted earlier, the only technological shortcoming of a sized yarn which is known to adversely affect weaving performance lies in the yarn's significantly reduced extensibility and breaking* *elongation after sizing*. Based on the above and previous discussions, it seems that the major areas of concern, or the anticipated problems, in sizeless weaving briefly are:

A. *Yarn Tension Inconsistency*. As previously mentioned,, the inconsistency of yarn tension in the spinning, winding, warping, beaming, and weaving operations is perhaps one of the most critical factors, which as yet has not been investigated or even recognized. In this reporter's view, the tension/stretch inconsistency among the several thousands different yarn strands comprising the loom beam can be and must be first taken care of either by using the proper technologies that are now commercially available or by certain modifications of the existing equipment and procedures, as briefly discussed later in this paper and as elaborated in the in-house work plan of the proposed research.

B. *Twist Liveliness*. A twist-lively sizeless yarn undoubtedly will not only be difficult to draw/knot on an automatic drawing/knotting machine (for preparing or replenishing a loom beam) but would also cause a seriously damaging "dancing" of the yarn in the heddle eye during shedding in weaving. Due to the repeated or cyclical stresses and strains in the yarn, the yarn dancing probably would cause a gradual loss of twist in the sizeless yarn, which ultimately could result in the yarn breakage and, hence, the loom stop. Historically, it has been perceived difficult, if not impossible, to set the twist torque of a single's warp yarn without the conventional sizing. However, it seems that it should be possible to set a cotton yarn by simply passing it through a hot or boiling water bath and then drying it, preferably under some sort of tension or pressure, either by hot air or on steam-heated cylinders.

C. *Hairiness and Abrasion Resistance*. Concerning the yarn hairiness and abrasion resistance, it seems that for a given yarn there is a maximum hairiness level above which it will not weave properly on a given loom for a given fabric style. Similarly, a warp yarn with its abrasion resistance below a certain level for the given fabric style and weaving conditions will not properly weave. By using a modern technology of condensing fibers for yarn consolidation by means of controlled air suction at the yarn delivery zone, it is possible to minimize ring yarn hairiness considerably. Also, a light lubrication of only the surface of a steam-set, sizeless cotton yarn may reduce to an acceptable level the yarn co-efficient of friction, which should minimize both the yarn clinging and abrasion during weaving. However, it may be stated that for efficient weaving there are certain requirements of minimum yarn friction and strength, maximum pick density, and minimum and maximum warp tensions.

If we can produce and "prepare" a smooth, strong and uniform cotton yarn (which we really should be able to do with the modern textile materials, technologies, machines and procedures that are now available) and, somehow, without the traditional sizing, stabilize the yarn torque, eliminate or at least minimize the yarn clinging, and minimize the yarn abrasion (yarn-to-yarn and yarn-to-loom component), it should be possible to weave the yarn without the traditional size application. Furthermore, if we could also simultaneously focus our attention to all other important and pertinent areas and directions (including but not limited to the factors relating to the yarn production and preparation, especially the yarn tension/stretch consistency throughout, and the weaving process and conditions) to enhance the weaving performance, we should at least be able to conduct an actual weaving trial with a sizeless cotton warp and possibly identify and even understand the problems encountered, if any. In other words, conducting an actual weaving experiment or trial on a commercial weaving machine *with an appropriately prepared sizeless cotton warp of the best possible yarn quality and preparation is imperative for* a "diagnostic evaluation" of *the sizeless weaving*. An actual weaving trial should enormously assist in classifying various warp-related yarn failures and loom stops and in determining their probable causes and/or origins. *Indeed, a "sizeless weaving" endeavor with the best possible yarns, the best possible yarn preparation, and the best possible weaving machine and conditions seems to be a must for evaluating the sizeless weaving.*

Undoubtedly, there are many, many yarn- and weaving-related factors that can also have a major influence on the incidence of loom stoppages and, hence, on the weaving performance and efficiency. As the saying goes, the weakest link in a chain actually determines the chain's performance or outcome. Therefore, it is imperative that we fully examine, understand, and try to address by all means all the known, logical, and suspected "weak elements" (problems) in the entire fiber-to-fabric production chain. It is critical that we first thoroughly examine and even try to optimize all the relevant yarn and weaving factors and conditions that supposedly would be good for sizeless weaving. Of course, we know that there is no one rule of thumb or application across the board for all types of yarns, weaving machinery, and fabric styles. High speed weaving especially must be considered as an integrated manufacturing system for which the spinning system and yarn quality, the yarn preparation, the loom type, the weaving conditions, the fabric style and its end-use application, and, of course, the cost effectiveness must be carefully considered in making a decision whether to go in for the conventional warp sizing, the semi- or low-sizing, the permanent sizing, or the proposed "sizeless" weaving. Not every yarn will run at the high speed a loom can run and, with the same token, not every loom can run at the same high speed that a yarn can run. The same also applies to the fabric style. Not every yarn and every loom can produce the same fabric style. The modern high-speed air jet and rapier weaving machines, compared to the traditional low-speed fly-shuttle looms, certainly require superior quality yarns that are made with superior raw materials and processing conditions.

There essentially are two broad ways to investigate sizeless weaving and seek ways and means to enhance its performance by trying to solve any anticipated, suspected and/or actually encountered problems:

1. One is to undertake the traditional basic research approach in which one would try to examine the individual effects and impacts of all the influential yarn properties (such as twist liveliness/torque, hairiness, abrasion resistance, tensile breaking strength, etc.) and weaving parameters/conditions on weavability or weaving performance of the sizeless warp yarns. With this approach, one would essentially study and quantify the independent effect or importance of each of the important yarn properties on the yarn weavability under typical sets of weaving conditions, fabric styles, and looms (running at typical speeds). This approach merely is a time consuming, costly, academic exercise which would require the research resources that presently are not available. Furthermore, the available test instruments for measuring yarn hairiness and abrasion resistance unfortunately are nearly impossible to calibrate and, hence, are unreliable. Frankly, there is no established scientific relationship between the yarn data from these instruments and the actual weavability of even "sized" yarns, since the "sizeless" cotton yarns have never been evaluated for their weaving performance on commercial looms. Only a limited work which relied only on laboratory testers such as Sulzer Ruti Tester and on other weaving simulation techniques has been reported.
2. The second and perhaps more meaningful research approach to investigate sizeless weaving is to conduct some specifically focussed or targeted actual weaving trials on a suitably modified modern weaving machine, using the best quality cotton yarns that the industry can now produce and prepare for weaving. In other words, by applying all the practical knowledge and even theoretical concepts about efficient weaving and using a good common sense approach to various other influential factors beside the yarn quality, one should be able to conduct a research-cum-test trial with a sizeless cotton warp to correctly define and classify various warp-related yarn failures and loom stops. An actual weaving trial should enormously assist also in expeditiously chalking out any future research. An exact characterization of the loom stops and their possible causes should shed enough light to enable an experienced scientist such as this reporter to identify specific areas of concern and research to try to accomplish the ultimate goal of efficiently weaving cotton warps without the traditional sizing or with a lower level of the traditional sizing.

Based on the above discussion, the extensive review of the literature on the traditional sizing and desizing, and the reporter's discussions with many other scientists, the proposed research plan and procedures mainly adhere to the second approach, although substantial yarn testing and research documentation of other influential factors will also be conducted for necessary analyses and confirmations of any new findings. The following is a brief description of the research/work plan to be undertaken to try to attain what so far has been perceived most difficult, i.e., weaving cotton warps without the traditional sizing.

## Research Plan and Procedures

As previously mentioned, the yarn spinning and winding (winding, warping and beaming) tension variations in the several thousands individual warp ends that comprise the loom beam, the yarn twist liveliness or torque, the yarn abrasion resistance, and the yarn hairiness are conceptually considered to be the most critical yarn-related factors in weaving sizeless cotton warp yarns. Accordingly, we will first try to improve by all means available these yarn parameters. Since open-end spun cotton yarns are well known for their superior "consistency" and lower hairiness compared to ring spun yarns, we will investigate both the OE and ring spun yarns for sizeless weaving on a modern flexible rapier loom. In each spinning category, we shall produce two yarn sizes, viz., a 30 tex and a 15 tex (20/1 and 40/1 Ne), of the highest possible yarn strength and quality, with minimum yarn tension variations within a package and among different packages, and with minimum number of knots and other yarn defects. We shall try to achieve the above yarn attributes by properly controlling the spinning process, i.e., by only producing partially filled bobbins/packages with only a small quantity of "flawless" yarn wound with an almost consistent tension on each package. The following is only a brief summary of the work plan (the details can be seen in the main project statement):

**1. Spinning**

First, we will spin, on both O.E. and ring spinning commercial machines, 30 tex and 15 tex carded and combed yarns of 100% cotton and 80/20 cotton/polyester blend. We shall try to produce the yarns of highest possible tensile strength, extensibility, and uniformity by implementing some or all of the following procedures:

i) selecting fibers of optimum quality (4 bales of Acala cotton and the required quantity of Dacron high tenacity polyester staple);
ii) using two rovings, per ring spinning unit, that are separated in the drafting zone to achieve the maximum effect of "doubling." Equivalent bicomponent yarns produced with the USDA-patented technology may also be evaluated for sizeless weaving;
iii) avoiding yarn piecing, i.e., any ends down will not be pieced and the partial bobbins will be doffed as such and directly taken to the winding process to minimize the resulting yarn imperfections and weak regions that usually are the potential causes of significant loom stops in weaving;
iv) minimizing yarn tension and, hence, stretch variations within and among ring bobbins either by using the new technology that is now available to control spinning tension on modern spinning frames or by spinning and doffing only small/partial bobbins (to maintain uniform/consistent yarn tension) on a conventional spinning machine. As discussed previously, one can appreciate the critical importance of yarn tension consistency onlywhen one retrospectly considers its adverse effect in weaving, where several thousands yarn strands with varying tensions are assembled on a loom beam. The strands wound with significantly greater-than-normal tension/stretch are likely to fail and cause loom stops;
v) minimizing yarn hairiness by means of a newly developed fiber condensing technique which uses a combination of a fine-mesh cloth screen and a controlled air suction in front of the front rollers on a ring spinning frame;
vi) producing a thoroughly interlaced yarn of improved abrasion resistance by using a compressed air nozzle in front of the front-roller nip;
vii) if feasible, producing a cotton-rich blend yarn using specially-shaped, serrated synthetic fibers to impart improved fiber-to-fiber anchorage and hence increased coherence.

**2. Quality Preparation of the Spun Yarns in Winding and Warping**

Since the yarn winding tension/stretch consistency throughout the yarn processing for weaving is believed to be critical, we will religiously take all the necessary precautions in the winding and warping operations to achieve the desired end-to-end tension consistency within and among different yarn packages/beams. Schlafhorst and Meuller recently have announced their new technologies to precisely control yarn tension in winding and warping, respectively. A weaver's knot with short tails and/or a good splice in both the winding and warping processes will also be essential for sizeless weaving. Full details of the winding and warping operations are given the in-house work plan supplement.

**3. Torsional-Setting and Surface-Modification of the Yarns**

We will try to set the yarn twist liveliness, improve the yarn abrasion resistance, and minimize detrimental effect of the yarn hairiness by separately preparaing the warps in the following three different ways:

i) by using either steam or simply hot (60C) or boiling water to set the yarn in a simple, *sizeless* slashing/beaming operation as described in the in-house work plan supplement Basically, in this *sizeless* beaming operation, the yarn is passed through a bath (size box) containing either hot (60C) or boiling water and either a wetting agent (to efficiently soften and shake the cotton's natural waxes (~0.6%)) or liquid ivory soap, or alcohol and then partially squeezed to expel some of the cotton waxes to the yarn surface for the desired lubrication. A small addition of Arabic gum may also be evaluated in the preliminary investigations, since the gum acts as a good binder and improves both the yarn modulus and tenacity. This ultimately should improve the abrasion resistance because the yarn modulus and tenacity are closely related to the yarn abrasion resistance. The yarn thus treated is dried on steam-heated cylinders, properly leased using a hook reed, and finally beamed maintaining ~ 0.5 % stretch.
ii) by using a prewetted and partially squeezed yarn (as in "b" above) in the conventional sizing process using a conventional size

formulation such as a PVA mix. This warp preparation approach should result in a significantly-lower-than-normal size add-on and, furthermore, most of the size add-on would be on the yarn surface, where it really is most needed and effective. Basically, the application of the traditional size to a prewetted yarn would mostly limit the size pick-up to the yarn surface only. The hypothesis here is that due to the presaturation with water, an appropriately prewetted and squeezed yarn could retain little size inside its structure (where the size may not be as effective anyway as on the yarn surface).

iii) by plying the 15-tex yarn and "kiss waxing" the plied yarn during beaming. Beside attaining an overall improvement in uniformity of a yarn's various/important properties, the yarn plying also balances the yarn twist, which minimizes the yarn torque and is essential for good weaving. A light waxing of the plied yarn during the beaming operation will reduce co-efficient of friction of the tarn, which, in turn, should minimize the yarn abrasion and failures during weaving. Hence, for purpose of a comparison and for better understanding of the sizeless weaving, a 2-ply of the yarn(s) will also be evaluated.

**4. Beaming (Extremely Critical)**

All precautions, including the use of a hook reed, will be taken to insure that there is no crossing of yarns on the weaver beam. Crossed ends indeed are a major source of loom stops and, hence, must be avoided at all cost. The yarn stretch, drying time/temperature, squeeze-roll pressure, and the yarn speed would be appropriately investigated and subsequently controlled religiously.

**5. Minimizing Yarn Abrasion/Torture During Weaving (By Means of the Following Loom Modifications and Weaving Adjustments and Conditions):**

i) Use chrome finished, glazed ceramic, or nickel plated heddles, drop wires, and reed.

ii) Slightly stagger the drop wires banks and the heald shafts to minimize yarn congestion and abrasion.

iii) Form a symmetric, as small as feasible shed in the front weaving zone between the heald shafts and the cloth fell.

iv) Use appropriate temples to firmly hold the fabric, so that the tension in the warp yarns under the temples is not considerably lower that of the body ends in the middle of the fabric.

v) Depending on the yarn and fabric construction, maintain optimum and uniform warp tension across the entire fabric width.

vi) Maintain at least 80% R.H. and 75$^o$ F temperature (preferably, 85% R.H. and 80$^o$ F) in the weave room. Absolutely no compromise, when weaving cotton yarns.

vii) Produce plain-weave and twill-weave fabrics of standard constructions on a modern flexible-rapier weaving machine, initially using the necessary modifications to accommodate the sizeless warp. Closely monitor the yarn performance and failures and try to immediately assess and remedy any remediable problem.

**6. A Limited "Weftless Weaving"**

Under the otherwise similar conditions of weaving with weft, we will conduct a limited "weftless weaving" exercise to determine any adverse effect of the weft insertion. In other words, we will study any particular effect of the "weft insertion" and hence the cloth formation on weaving performance of the warp. Since, the warp abrasion in the weftless weaving experiments should remain almost the same as in the weaving experiments with the weft, any gain observed in the warp performance in the weftless weaving may indicate any possible adverse effect of the warp yarn hairiness on the filling insertion in the actual weaving with the weft. Any new information gained through these exercises may be used to address problems in the future research.

**7. Testing**

All testing of the various yarns and fabrics will be conducted according to established ASTM, AATCC, or SRRC test methods and procedures.

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