2004 BELTWIDE COTTON CONFERENCES, SAN ANTONIO, TX – JANUARY 5-9

AN UPDATE OF SIZE-FREE WEAVING RESEARCH AT SRRC

Paul S. Sawhney, John B. Price, Timothy A. Calamari, and Navzer D. Sachinvala
USDA-ARS
Southern Regional Research Center
New Orleans, LA

Abstract

About three years ago, a totally new ARS research project (CRIS) on size-free weaving of cotton yarns was approved and initiated at SRRC. The initial program, based on experimentation with a conventional fly-shuttle loom, has been surprisingly successful in the sense that 50 meters of a 100% cotton fabric of a relatively less-dense construction was efficiently woven without the warp sizing and without a single warp yarn failure during weaving, for the first time ever. Since the American textile industry now does almost all of its weaving on modern high speed weaving machines, which are significantly different from the conventional weaving machines and, hence, can affect size-free weaving performance considerably, the size-free weaving research at SRRC is now being expanded to include a modern Pignone (Sulzer-Ruti) high speed flexible-rapier weaving machine that the Center has recently acquired. This report is a brief description of the past research and of the new research plan that involves size-free weaving investigations of different types of fibers, yarns and fabrics, using the new weaving machine.

Introduction

Since time immemorial, cotton warp yarns (singles) have always been temporarily sized or coated with some sort of adhesive, such as an ordinary corn starch, Carboxymethyl Cellulose (CMC), or polyvinyl alcohol (PVA), along with several other chemicals, to achieve efficient weaving. The sizing assists weaving mainly by: 1) setting the yarn's twist torque and suppressing its hairiness; 2) improving the yarn's abrasion resistance against the adjacent yarns and against the loom's metallic components/mechanisms that cause harsh mechanical actions during weaving; and 3) increasing tensile strength of the yarn. However, the chemicals used in a size mixture interfere with the subsequent processes, such as fabric bleaching, dyeing and/or any special finishing, and thus adversely affect fabric quality. Therefore, the size ingredients must be completely removed from the fabric at the first opportunity by a fabric desizing process. Both the warp sizing and the fabric desizing use, or rather waste, tons of expensive chemicals, consume a lot of energy and water, and generate a large quantity of waste water which now must undergo an expensive treatment for its safe disposal. This makes both the processes very costly, complex, and environmentally sensitive. Today's ailing textile industry wants to eliminate the main, underlying process of warp sizing to reduce manufacturing costs and improve industrial ecology. The National Cotton Council of America (NCCA) has categorized "size-free weaving" as a priority research project to resolve one of the most serious and complex problems encountered in the production of woven cotton fabrics (Burlington Industries 1981).

Although a good volume of research has been conducted for more than a century to improve basic sizes, sizing formulations, and slashing machinery and practices to improve weaving efficiencies of staple yarns, no significant work (other than the recent preliminary work by ARS and some past contributions of UMIST in 1970's) on ***eliminating warp sizing*** has been conducted and/or reported in recent years (Clapp 2001; El-Mogahzy 1999; FCTR 1998; Moreau; Perkins 1999; Sawhney et al., 2000; Vincent and Gandhi 1974; Vincent and Gandhi 1976a; Vincent and Gandhi 1976b). ***Frankly, for all practical purposes, the so-called "sizeless or size-free weaving" of cotton yarns simply does not exist today.*** To the best of our knowledge, no institution within or outside the ARS is presently involved in research to solve this most serious and complex problem of size-free weaving. In fact, we are not aware of any major institution worldwide, which currently may be conducting research to eliminate warp sizing. A few researchers recently have attempted to either reduce conventional warp sizing or replace it with some sort of permanent sizing which would not interfere with the subsequent chemical processes and which would beneficially stay on the fabric during its entire useful life. However, for one reason or another, these research studies so far have not had the desired impact on the industry. Size-free weaving, if commercially successful, is likely to shorten the traditional processing chain of transforming cotton into woven textiles, reduce the cost of production, and significantly contribute to improving the ecological balance. A shortened, cost-effective, and environmentally-safe cotton textile processing chain will make cotton textiles more competitive, which eventually could favorably impact utilization and hence demand and price of cotton to economically benefit the cotton producers. The size-free weaving can be expected to improve profitability of the domestic textile industry, which **may** even revitalize the industry. As we know, the industry currently is suffering from a host of very serious issues, including severe economic pressures generated by the mounting, relatively less expensive textile imports from some developing countries of Asia, Eastern Europe, Mexico, and South and Central America. The size-free weaving (along with the recent significant improvements in the fiber and yarn processing, overall) of certain, large-volume, commodity-type fabrics (such as denims and sheeting, where the labor content could easily be reduced to an insignificant component in the fabric cost structure) of high quality could make a difference in the present difficult situation of the domestic industry. Although the strength of the size-free weaving project may still not be as much in its ability to improve the industry's competitiveness against the imports as in improving the industrial environment, the overall benefits of success in commercial size-free weaving are huge. The size-free weaving ultimately can offer significant economic benefits to both producers and users of cotton.

Review of Progress in Size-Free Weaving at SRRC: Research Approach

Due to certain constraints in the available resources and also for sake of efficiency, we developed a multi-pronged research approach for a preliminary investigation of size-free weaving, using a fly-shuttle loom. A disadvantage of this approach was that it simultaneously involved several potentially influencing factors, which inhibited determination of individual impact of the various factors. Those factors were:

1. ***Yarn quality (type and characteristics)*****:** To achieve the best possible weaving results, we selected the open-end spinning route to produce a rotor-spun combed cotton yarn of desirable attributes and of good and consistent quality, using Acala cotton.
2. ***Yarn Preparation*****:** To set the yarn twist torque and also to improve yarn strength, we treated the warp sheet in a bath of boiling water containing a wetting agent, followed by drying the sheet under a nominal tension. A uniform, consistent tension of individual yarn strands was ensured throughout the yarn preparation, especially the warping.
3. ***Modifications of loom components*****:** The loom reed, heddles and drop-wires were coated with a film of Teflon to minimize yarn abrasion, and hence damage, during weaving.
4. ***Fabric construction and weaving conditions*****:** A fabric construction of relatively low thread density was purposely selected to reduce yarn-to-yarn and yarn-to-metal abrasion, in order to reduce the overall yarn stresses in the initial weaving to demonstrate the feasibility of size-free weaving.

Materials and Methods

We used good-quality Acala cotton to produce a rotor-spun combed cotton yarn (Ne 20/1 or 30 tex) of excellent quality for both warp and filling. The warp yarn, which was monitored and cleared of its major defects on the spinning machine, was warped onto several section beams. Precautions were taken to maintain an almost consistent tension of 12 grams on individual yarn strands in the warper creel, which produced section beams of uniform yarn tension. The section beams were assembled in the creel of a "dummy" slasher, which did not involve use of any size mixture. The yarn sheets from the section beams collectively passed through a bath of boiling water containing rice soap and wetting agent (humectant). The so-called washed yarn, under a nominal tension, was dried and, hence, "twist set" by passing it over three large steam-heated cylinders or cans at 220 F. The dried/set yarn was lightly kissed with a lubricant before being wound onto a loom beam. The moisture regain of the yarn on the beam was controlled around 6%. The beam was mounted onto a Draper 52" wide, XP model loom. Since warp yarn abrasion is particularly critical in size-free weaving, the loom reed, heddles and drop-wires were specially coated with Teflon to minimize the yarn abrasion during weaving. A weaving trial was conducted at 190 picks per minute under mill-like conditions to produce a twill fabric of relatively less dense construction (52 epi x 40 ppi). The weaving process was monitored for performance by recording any warp yarn failures, by observing warp yarn abrasion, hairiness, and any lint generated, and by examining the shed formation for its cleanliness.

[It may be mentioned here that the primary author of this paper theorizes that ***any inherent, significant variations in the tension and strength of certain yarn strands (in the warp sheet on a loom beam) may be the sources or causes of certain warp yarn failures during weaving.*** It is postulated that the "fabric take-up" and the "yarn let-off" mechanisms of a conventional loom may also be partly responsible for these yarn failures by progressively causing certain, initially taut warp yarns (on the loom beam) to get even tighter as the weaving progresses and the yarns race from the beam to the cloth fell. This is so, because the cloth take-up mechanism of a loom has a relatively much more precision than the loom let-off mechanism. The let-off mechanism only (crudely) senses the tension/pressure of the entire warp sheet and not that of the individual strands (i.e., the taut yarns in reference). So, if and when the tensile and frictional stresses of any of the taut yarns exceed the strand's endurance limits or thresholds, the strand fails and the loom stops. However, it should be noted that we still have not been able to accurately validate the above theory, mainly because of the difficulties experienced in the ***electronic measurements of the dynamic or running tensions of several individual yarns simultaneously during actual weaving].***

Results and Discussion

More than 50 meters of a100% cotton fabric was successfully produced without the traditional warp sizing and without a single warp yarn failure for the first time ever. This indeed is a very significant and pioneering milestone in textile processing research. Although the warp exhibited progressively increasing hairiness (which obviously was visibly maximum in the reed-sweep region, where the two components of the warp shed are in close proximity to each other), the increased hairiness absolutely did not interfere with the shed formation and create the anticipated and most feared problems of fiber-to-fiber clinging or yarn-against-yarn snagging. This may be attributed to the fact that there essentially was no adhesive of any kind (neither the conventional size nor the cotton's natural sugars and waxes, etc., which presumably were uniformly dissipated or simply washed away during the wet cleaning of the warp in boiling water) present on the warp yarns, which could have triggered the said problems. The relatively low thread density and loom speed could also have played favorable roles. At any rate, the weaving process in this preliminary study did not reveal any warp-related difficulty or problem, which makes us feel confident that the size-free weaving is feasible for at least some types of fibers, yarns, fabrics, and weaving conditions.

Current Research Plan

As mentioned previously, the multi-facet research approach (which was intentionally adopted for sake of efficiency and quick results), although it surprisingly yielded the most encouraging results in a preliminary size-free weaving trial, had one significant disadvantage. Because of lack of proper individual controls of the various influencing factors involved, we did not and still do not exactly know which factor or factors really had the most significant impact. Therefore, to properly ascertain the relative significance or impact of each of the individual major factors, we are now expanding size-free weaving investigations to study one major influencing factor at a time, using a modern high speed shuttle-less weaving machine. The weaving machine obviously would be the first new variable or factor to be properly identified and characterized. Any obstruction in the free movements of the warp and filling yarns on a modern high speed, shuttle-less weaving machine is much more detrimental (by way of causing an unnecessary yarn failure, machinery stoppage, and/or fabric defect) than on a conventional shuttle loom. Therefore, the planned investigations on a shuttle-less machine are expected to shed additional light to determine the future prospects of size-free weaving of cotton and other spun yarns. We are also poised to study the effects of different types of fibers, yarns, fabrics, and weaving modifications (coatings, speed/s, and other conditions) to gain new, fundamental knowledge that is essential to achieve the research objectives and to determine the feasibility of size-free weaving. Accordingly, the following is the plan of work to demonstrate the commercial scope of size-free weaving:

Phase A

1. Using Acala cotton, we will produce about 150 pounds of a rotor spun combed cotton yarn (20/1 Ne/30-tex), using 4.54 TM. We will set the comber to extract ~ 15% noils. The yarn will be cleared on Schlafhorst Autocoro to a level equivalent to Classimat A4 to D4 major faults. We shall ensure uniform yarn package size for warping. Just for the sake of this experiment, we shall discard any yarn package of significantly abnormal size to ensure consistent yarn tension.
2. We shall prepare 10 warp section beams of ~ 320 ends in each, ensuring a constant running tension of ~ 12 g for each strand. The creel would be properly prepared to ensure consistent yarn tension.
3. Preparation of a loom beam on a (dummy) slasher. The beam will comprise of the following yarn sections/treatments:
   a. About 50 yards of the warp yarn on section beams will be wound on to the loom beam without any special treatment, i.e., <u>no immersion in boiling water and no heat treatment by the cylinders</u>. However, normal use of hook reed, lease rods, comb, etc., will be done to achieve a uniform lay of about 3200 ends on the beam. We shall try to minimize yarn stretch (less than 1%) and maintain ~6% moisture content during beaming.
   b. The next 50 yards of the warp will be treated as in "a" above, except that this segment will pass over the steam-heated (210 - 220 F) cylinders to simply heat set the yarn and possibly fuse/melt cotton's natural sugars and waxes and spread them to uniformly coat/lubricate the yarn surface. <u>The yarn will not go through boiling water in this exercise</u>.
   c. The next 50 yards of the warp will be immersed in boiling water (containing a wetting agent and possibly rice soap w/ a defoamer) followed by drying on the steam-heated cylinders, before being wound on to the beam. This process is expected to set the yarn twist torque, which is essential for weaving. This may also dissolve cotton's natural sugars and waxes, which, in turn, may uniformly lubricate the yarn surface and thus assist weaving.
   d. The next segment of 50 yards of warp is a repeat of item "a" above.
   e. The next 50 yards is a repeat of item "b" above.
   f. The next 50 yards is a repeat of item "c" above.
   g. The final segment of 50 yards (on the top of the loom beam) will have a regular 6% PVA size add-on.
4. Starting with the conventionally sized warp yarn, initial weaving will be conducted on the new Pignone weaving machine as it is, i.e., without any modifications of any loom components, operating at various speeds (200 thru 500 ppm, in order to study the effect of weaving speed). The fabric construction and other weaving conditions will remain almost the same as in the previous weaving exercise on a fly-shuttle loom. The weaving will continue in similar manner and be properly monitored for its performance with each of the next three differently prepared warp segments. After experimenting with the above 4 segments and depending on the success of the experiments, <u>we shall change over the weaving machine to accommodate specially finished reed, heddles and drop-wires</u> and continue the weaving and monitoring of the next 3 segments similar to that described for the last three warp segments. This exercise will give us some indication of the impact of the modified loom components.

[Contingency: We expect success in some of the above size-free weaving trials. However, if the outcome of the so-called "weaving machinery study" is unfavorable, we will try to find the "culprits" and provide answers to resolve them. This may involve an appropriate redirection of research to basically determine: i) causes (and possible cures) of the yarn failures during (size-free) weaving; ii) optimum fabric construction (lighter) that could be efficiently attained at the machine's weaving speed (ppm) at which a standard fabric construction could be efficiently woven without the traditional warp sizing.

Phase B

If Phase A yields reasonably satisfactory results, as we expect, we shall proceed to Phase B and beyond to explore commercial feasibility of size-free weaving. The research conducted under phases B, C, D and E would let us evaluate comparative weavabilities, under mill-like conditions, of different types of yarns for classic fabric constructions and weaves. Specifically, Phase B is designed to evaluate size-free weaving of the most common or conventional type of commercial yarns produced by the ring spinning technology. In this phase, the recently developed *compact-spun yarns* and the regular ring-spun yarns, both produced by the *combed cotton system*, will be evaluated, while keeping all of the other influencing factors (such as the yarn preparation, the fabric construction, and the weaving machinery and conditions) unchanged at the "ideal levels" determined in the previous, successful size-free weaving study.

Phase C

In Phase C, we will explore the feasibility of size-free weaving of a rotor spun *carded cotton* yarn. The carded yarns, in general, are inferior in quality, less expensive, and much more common than the equivalent combed yarns. However, compared to carded ring spun yarns, the carded rotor spun yarns are more uniform and have certain other characteristics that are deemed desirable for size-free weaving. Accordingly, we expect some degree of success in this particular weaving exercise. Again, the experimental procedures would remain the same as discussed previously, except that if and when any new, worthwhile observation or discovery is made during the weaving experiments/trials, an appropriate redirection of the research may be sought in consultation with the appropriate authorities involved.

Phase D

In Phase D, we shall evaluate weavability of both the compact- and conventional ring- spun, carded cotton yarns. The carded compact-spun yarns have certain physical characteristics that seem to be desirable for size-free weaving. For example, they are much less hairy, more abrasion resistant, and about 15% stronger than equivalent conventional ring-spun yarns (Vincent and Gandhi 1976c). Therefore, they are expected to show a favorable weaving performance, particularly in conjunction with our recent research developments in size-free weaving. On the other hand, the conventional carded ring spun yarns, because of their certain undesirable characteristics (especially, the inconsistencies and non-uniformities of the properties) are expected to pose significant difficulties in size-free weaving. However, we are prepared to precisely determine the exact nature of the problems that we may encounter and find solutions and remedies.

Phase E

Concurrently, as and when we achieve reasonably satisfactory weaving results in any of the above research Phases, we shall evaluate quality of the fabric(s) produced. We shall collaborate with the industry (cotton textile mills) to try to transfer any new technology developed. We may also consider developing a Yarn Endurance Tester to objectively assess weavability of a warp yarn without actual weaving. An outline schematic of the instrument is shown in Figure 1. The initial, underlying purpose of this development really is to expedite research, since an actual weaving trial (under the existing conditions) to study just one parameter takes months, if not a year. The instrument will be useful, provided we can establish a good correlation between the yarn's actual weaving performance and the yarn's endurance level (cycles till the yarn ruptures, or some other endpoint or indicator) as determined by the instrument. And that can be established only if and when we have a sufficient database on the actual weaving performance and the corresponding objective endurance limits or thresholds of several different types of yarns.

The progression of future work is summarized in a time-line chart, Figure 2.

References

Burlington Industries, Inc., (Illman et at.) Greensboro, NC. Method for hot-melt sizing yarn, United States Patent No. 3,990,132, November 9, 1976; Re 29,287 July 5, 1977; 4,253,840 March 3, 1981; 4,540,610 September 10, 1985; 4,401,782 August 30, 1983; Re 30,474 January 6, 1981.

Clapp D. M. Evaluation of Suessen Elite Compact Ring Spinning. Cotton Incorporated Research Report; No. 2001-1 (2001).

El-Mogahzy, Y.E. Personal communications, March 1999.

Focus on Cotton Textile Research, Issue No. 33. Published by National Cotton Council of America and The Cotton Foundation, Memphis, TN, 1998.

Moreau, J.P., Polymeric Sizing Agents for Cotton Yarn, Textile Chem. Color. **13**, 27 3-278 (1981).

Moreau, J.P. Evaluation of fabrics woven with durable polymeric sizing agents, Textile Res. J. 56 (10) pp 627-634.

Perkins, W.S. New slashing technology promises big benefits. Textile Chemists & Colorists. Pp 13-15. May 1999.

Sawhney, A.P.S., Parikh, D.V., and Parachuru, R. Preparation and weaving of cotton yarns without the traditional warp sizing- some new concepts. National Cotton Council, Memphis, TN. Beltwide Cotton Conferences; p 820-827, 2000.

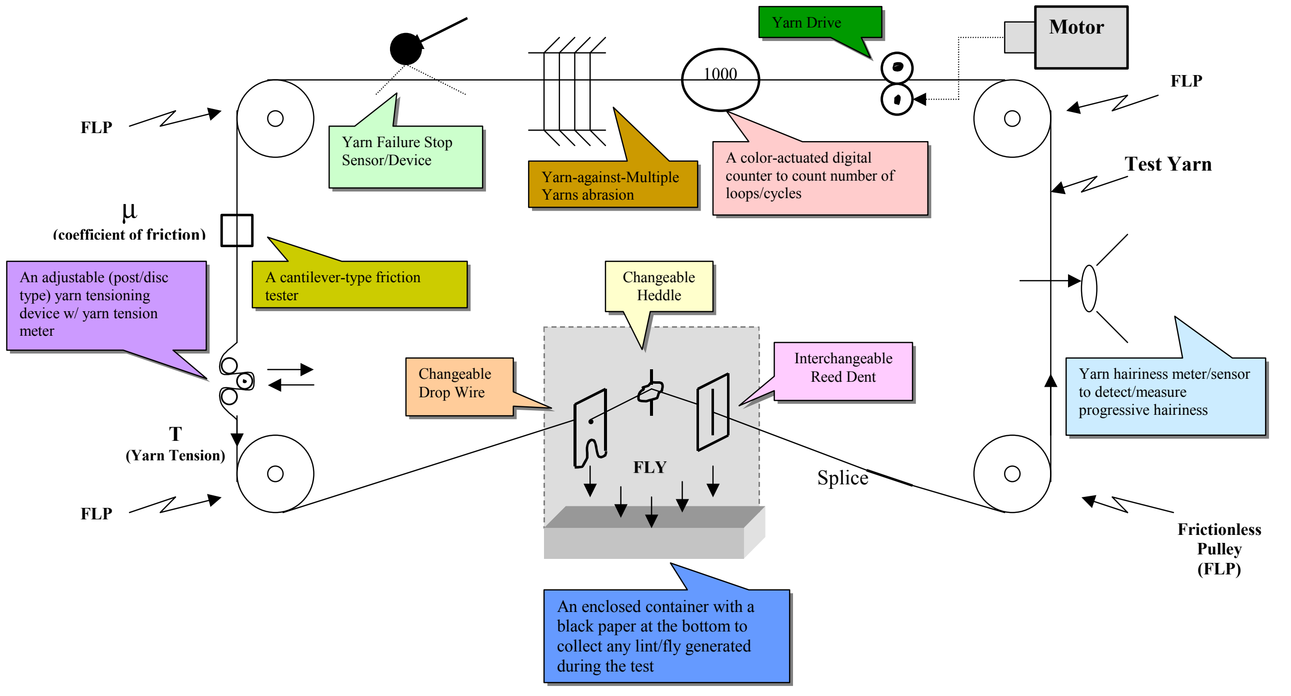
Vincent, J.J. and Gandhi, K.L. Singeing as a Substitute for Sizing - A letter to the Editor. Textile Institute and Industry, 12, No. 1; p. 17; 1974.

Vincent, J.J. and Gandhi, K.L. The Significance of Hairiness in the Weaving of Open-end Warp Yarn. Part I: Detrimental Effect of Protruding and Detached Fibers. Textile Institute and Industry, 14, No. 6; p. 191-192; 1976(a).

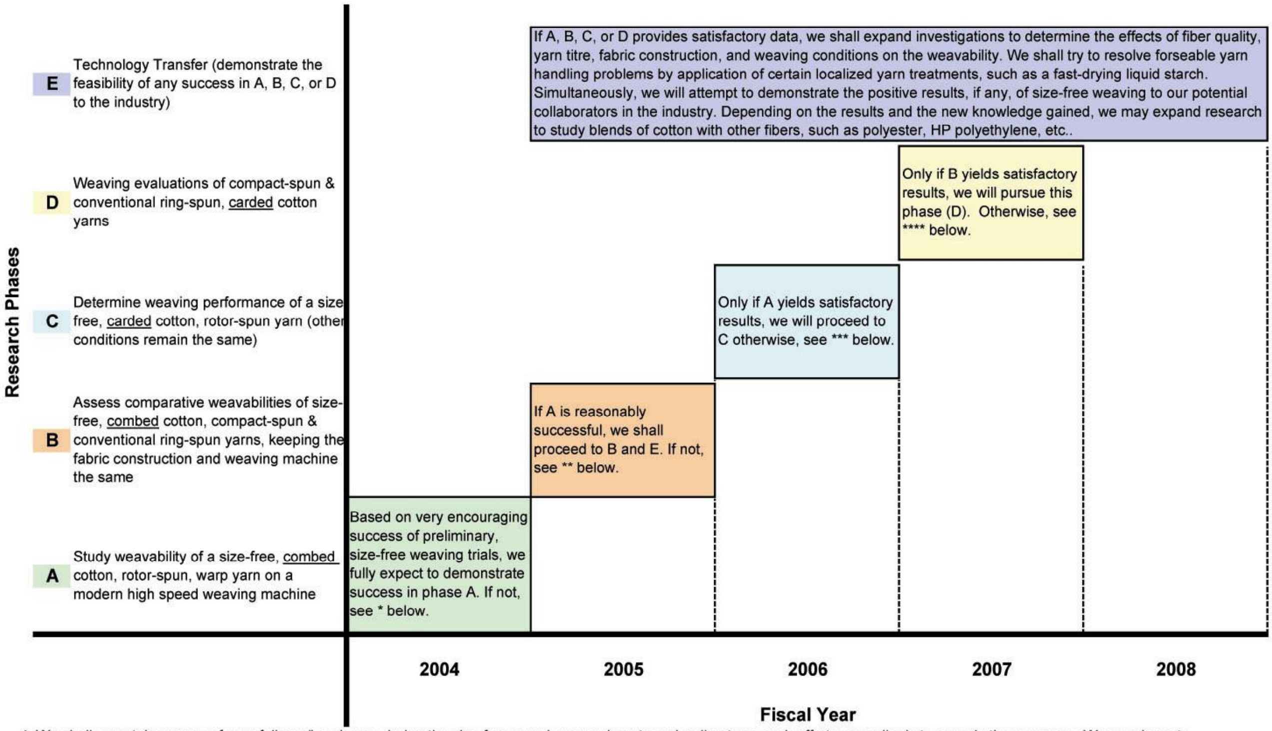
Vincent, J.J. and Gandhi, K.L. The Significance of Hairiness in the Weaving of Open-end Warp Yarn. Part II: Techniques for evaluating the relevant factors. Textile Institute and Industry, 14, No. 6; p. 192-194; 1976(b).

Vincent, J.J. and Gandhi, K.L. The Significance of Hairiness in the Weaving of Open-end Warp Yarn. Part III: The Suppression of Hairiness. Textile Institute and Industry, 14, No. 6; p. 194-196; 1976(c).

A Yarn Endurance Tester to Assess the Yarn Weavability



(A self-explanatory schematic-design of a versatile "Yarn Endurance Tester" to quickly assess, beside the overall yarn quality and endurance, the weaving performance (weavability) of a yarn without actual weaving)



* We shall ascertain causes of yarn failures/breakages during the size-free weaving experiments and redirect research efforts accordingly to remedy those causes. We may have to comprehensively study the effects of various yarn attributes, fabric constructions, and weaving conditions on the weavability.

** We will explore the effect of water vapor (moisture/lubricant) on the warp during weaving.

*** We will explore relatively lighter fabric constructions and easier fabric structures (weaves), possibly along with minimal reduction of loom speed.

**** Based on any new knowledge gained, we shall try to develop a fundamental understanding of yarn failures during size-free weaving and further improve yarn abrasion resistance and reduce actual yarn abrasion during weaving by new ways and means. In this phase, we may have to resort to the development of a new "Yarn Attrition Tester" to quickly assess weavability of a size-free staple yarn without actual weaving. Depending on the resources available, we may also explore the feasibility of producing a super quality denim fabric without the traditional warp sizing and, possibly, warp dyeing. It may be emphasized that at any time if the results appear to be totally unacceptable and we feel that the future prospects are not promising, we shall either immediatly terminate the program or develop totally new and unconventional research approaches to develop new yarns and seek modifications of weaving machinery. In that case, we must resort to the development of a new test instrument to rapidly assess yarn weavability without actual weaving (please see the attached schematic).