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Weavability of Cold-sized Worsted Warp Yarns

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Abstract

Production of light weight high quality worsted fabric needs fine count single warp yarn. Single worsted yarns are highly extensible and have too much hairiness to be woven as warp. Sizing is essential to make these yarns weavable. Conventional sizing is not suitable for woolen/worsted warps because of their stretchability and heat sensitivity. Cold sizing is found to be one of the alternatives to solve this problem. However, selection of appropriate size composition and application technique are key parameters for successful weaving of these yarns.

Key Words: Bending rigidity, Extensibility, Hairiness, Tenacity, Weavability

1. Introduction

On the weaving machine, the warp yarns are subjected to several types of stresses i.e. cyclic extension, flexing, abrasion at various loom parts and inter yarn friction. To ensure less number of breaks, the warp yarn must withstand these complex actions. At the same time, weaving technologists have to understand the behavior of warp, when they are subjected to these complex stresses [1]. In order to know effect of these actions, it is essential to study the breakage mechanism of warp yarns. It is well known that the breakage of spun yarn normally occurs either due to inter-fiber slippage or due to fiber breakage [2]. Unlike the short-staple spun yarns, worsted yarns show a different behavior with regards to weavability and breakage phenomenon. This is because, the staple length of wool fibres may be as high as 7 cm in contrast to a length of maximum 4 cm in case of cotton. Longer staple length produces high yarn elongation. This large extension makes yarn unweavable before the yarn actually collapses. Because, after a certain extension the yarn stops taking the weaving load and hence acts as a collapsed thread and this failure is called as a pseudo-break.

A shift towards the use of light weight suiting fabrics has already been observed world over. Also there is a trend to produce natural fibre based non-conventional blends like wool:linen, wool:silk, wool:tassar, wool:cotton etc. Suitings are now preferred in the range of 150–220 g/m^2 in contrast to conventional 250–350 g/m^2. The challenges in this direction are availability of finer count and better quality single yarn, development of suitable size recipe and sizing technique to enable it for weaving on high speed shuttleless looms. Sizing is not very common in wool and worsted sectors as the normal practice is to use two or multifold yarns which do not require any sizing. However, because of new trend of fashion towards light-weight fabric, it has now become important to use single sized worsted yarn for achieving desired weavability. Conventional aqueous sizing is not very attractive for woolen/worsted yarns from economics, ecology and fabric quality point of view. In this context cold sizing of single worsted yarn during warping/beaming is suggested to be a better alternative for economic yarn preparation [3–5].

During sizing, size-fiber interaction improves structural stability, constituent fiber integrity and therefore, weaving stress bearing capacity of yarn. Degree of improvement in this stress bearing capacity mainly depends on nature of size-fiber interaction, which in turn depends on adhesion force between fiber and size, size penetration as well as encapsulation of yarn. Changing size add-on and some process parameters like squeeze pressure, roller hardness and chemical nature of size material can vary the size penetration and encapsulation. Besides all these parameters, size-fiber interaction largely depends on polarity of fibre and size material, yarn structure and properties. Single worsted yarns have a lower tensile strength as compared to equivalent 2-ply yarns. These can be weavable only through a sizing process [6]. The technique of conventional sizing is not suitable for wool based yarns due to its sensitivity

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towards high temperature and moisture. Thus a cold sizing operation involving non-aqueous based size recipe might be suitable for worsted yarns [7].

The warp breakage mechanism and weavability of conventional staple yarn produced on ring and open-end system are studied by several authors [1, 2]. Literature on non-conventional worsted yarn weaving performance is scanty. The sizing in woolen and worsted sector is yet to be practised to impart higher weaving performance for single worsted yarn. However a few authors have made some exploratory work to size wool and worsted yarns [6, 7]. It is therefore necessary to investigate the weavability of these yarns both before and after sizing. There is a need to find out alternative yarn preparation method for these yarns. The present research aims at preparing suitable warp to impart better weavability so as to produce fine quality light weight suiting fabrics out of them.

2. Materials and methods

2. 1 Materials

2.1.1 Yarn samples

A wide range of yarn samples were developed on state of the art worsted spinning systems of reputed industries. Both 2-ply yarns and equivalent single yarns were developed for purpose of comparison using a wide variety of natural fibres like 100% wool, 100% silk, wool:tassar, wool:silk, wool:linen, wool:cotton, silk:linen compositions. The specifications of yarns developed for study of weavability are given in Table 1.

2.1.2 Size recipes

The size recipes used consisted of modified corn starch and PVA along with some cold size recipes. The specifications of the cold size recipes are given below in Table 2.

2. 2 Methods

2.2.1 Evaluation of fibre properties

The fibre tensile properties were evaluated on Instron tensile tester as per ASTM D 3822–01. Kawabata Evaluation System KES FB2, bending tester was used to measure the bending rigidity of fibres. Paper windows of 0.1 m length and 0.01 m width were prepared for this purpose. The no. of fibres taken per window is 10 and maximum curvature is 250 m^{-1}. Fibre diameter was measured using projection microscope. Denier value for all types of fibre samples was calculated by taking weight of a known length of fibres using a digital balance.

Table 1 Yarn samples developed.

Sl. No.	Yarn Samples	Blend Composition	Count (Tex)	Sl. No.	Yarn Samples	Blend Composition	Count (Tex)
1	Wool	100%	1/25	13	Wool:Linen	70:30	1/42
2	Wool	100%	2/12.5	14	Wool:Linen	70:30	2/21
3	Wool	100%	2/20	15	Wool:Cotton	65:35	1/50
4	Wool:Tassar	80:20	1/20	16	Silk:Linen	80:20	2/17
5	Wool:Tassar	80:20	2/10	17	Wool: PET	50:50	2/26
6	Wool:Tassar	70:30	1/20	18	Wool:Nylon	80:20	2/45
7	Wool:Tassar	70:30	2/10	19	Wool:Acrylic	32:68	2/19
8	Wool:Tassar	60:40	1/20	20	Silk	100%	1/50
9	Wool:Tassar	60:40	2/10	21	Silk	100%	1/83
10	Wool:Silk	70:30	1/20				
11	Wool:Silk	70:30	2/10				
12	Wool:Silk	50:50	2/18				

Table 2 Specifications of cold size recipes.

Properties	Physical State	Appearance	Viscosity at 30°C	P^H	Solubility	Solid Content	Chemical Constituent
Cold Size 1	Viscous Liquid	Clear	20 $\pm$2 seconds	4-5	Soluble in cold water	6%	Poly Glycol Ether
Cold Size 2	Solid Wax	Hazy	-	-	Soluble in warm water	100%	Poly Ethylene Ether
Cold Size 3	Viscous Liquid	Reddish/ Brownish	20$\pm$2 seconds	6.5 – 8.5	Soluble in cold water	6%	Polyol Ether
Cold Size 4	Viscous Liquid	Clear to slightly hazy	18 $\pm$2 seconds	5-6	Easily soluble in cold water	6%	Poly Glycol Ether

2.2.2 Adhesion test

In order to test the compatibility of a size recipe with a particular fibre substrate, the rovings of 100% cotton, polyester-cotton and worsted materials were sized with all above size formulations and subsequently tested for their breaking strength on Instron tensile tester.

2.2.3 Yarn sizing

All yarns were sized by normal sizing technique using modified starch and PVA solution on the laboratory Zell sizing machine. The sizing machine speed was maintained at 5 m/min. A squeeze load of 500 N/m was maintained. The size paste concentration was 6%.

The process of cold sizing was also carried out with a cold sizing kit which is designed and developed in the laboratory, shown in Fig. 1. This is integrated with a sectional warping machine between the creel and the headstock. It works on tangential application principle but with slight modification. An extra light weight top roller is kept over the tangential roller to have slight penetration and better encapsulation of the yarn. The yarn is then wound over the warping drum immediately after application of liquor without any contact drying. The liquor base evaporates at room temperature leaving the solid material on the yarn surface. Finally the warp sheet is wound on the beam. The cold sizing process parameters maintained are: speed- 2–3 m/min, method- Single applicator roller system with light weight squeeze roller, distance between cold sizing kit and headstock- 2 m, solid content in size solution- 6%.

2.2.4 Yarn testing

The yarn hairiness was tested on the Zweigle hairiness tester. The instrument works on optical principle and counts the number of hairs of different lengths starting from 1 mm to the highest length as set during test of a particular yarn.

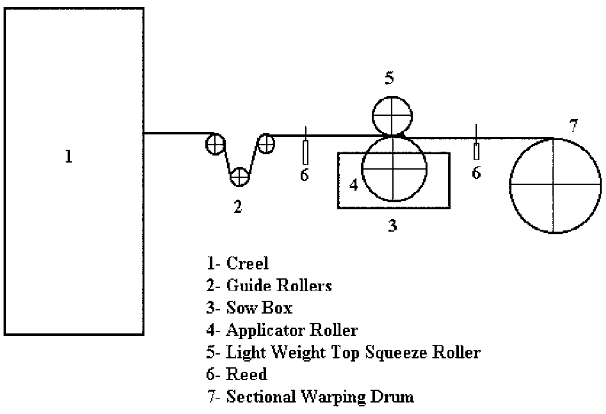

Fig. 1 Schematic of cold sizing kit.

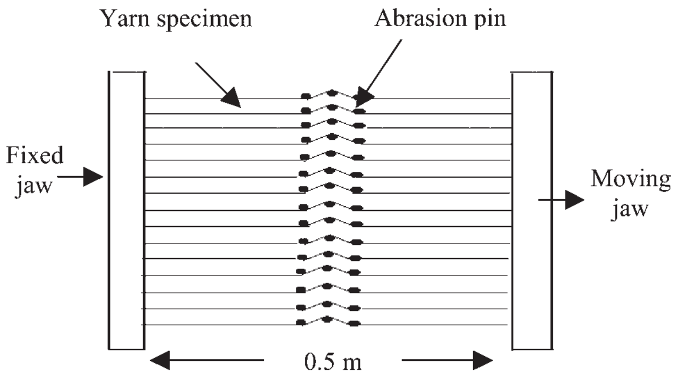

Fig. 2 Working principle of Reutlinger webtester.

The test length taken was 200 m, yarn speed- 100 m/min. The tensile properties of the yarns were tested on Instron tensile tester maintaining standard testing conditions as specified in ASTM No. D–2256–02. Yarn bending rigidity was tested on the Kawabata pure bending tester (KES FB2). Yarn samples were prepared into windows of 0.2 m length and it was tested on the instrument using: No. of yarns in a window- 20, Window width- 0.01 m (Test length of yarn) and Curvature- 100 m^{-1}.

In order to know relative weaving potential of yarns spun from different blends and establish a relationship between their structure, properties and performance, these were tested on Reutlinger Webtester, as shown in Fig. 2.

This instrument simulates all major stresses occurring during weaving such as cyclic extension, axial abrasion, flexing and bending. Like a loom, above-mentioned weaving stresses are applied simultaneously on a sheet of parallel threads held at pre-selected constant tension. Instrument records cycles required to break each thread along with thread extension corresponding to each break. The average number of weavability cycles of each sample was found by taking the average of the number of cycles recorded for first 10 thread breaks on webtester. For every break, load is decreased by $1/15^{th}$ of the initial preset load in order to maintain constant tension on each yarn throughout the completion of test. During test, if some yarns elongate and become slack, they do not experience fatigue and abrasion. Since such slack ends do not have any serviceability on loom, are called as pseudo-breaks. Therefore, they are manually removed at the cycles at which they become slack and a break is recorded on the instrument. Other necessary test details were kept as: Specimen length- 0.5 m, Initial mounting Tension/thread- 0.005 N/tex, Cyclic Extension- 0.5 %, Penetration of Abrading Pin- 0.003 m, Fatigue Speed - 300 cycles/min, Number of Tests/sample- 60. The progressive failure of the yarns on the weavability tester was studied by noting down and subsequently plotting the corresponding extensibility for each yarn failure after a definite number of abrasion/flexing cycles on the weavability tester. The failure mechanisms of yarns were also studied by taking photomicrographs under the Leica microscope interfaced with the Canon camera.

3. Results and discussion

3. 1 Adhesivity of size materials

In order to select appropriate size composition and method for the worsted yarns, initially a study was carried out to evaluate some of the commercially available size materials for their affinity towards cotton, PC and worsted material. The results of this adhesivity test are shown in Table 3.

PVA proves to be the best adhesive material for all kinds of fibres followed by Cold Size composition 4. Polyester-cotton in general shows better adhesivity in comparison to 100% cotton or worsted material, when sized with almost all kinds of size recipes. For worsted material, PVA and Cold Size 4 can be used as sizing adhesives. The adhesion force of Cold Size 2 with worsted material though higher, it has other disadvantages like stickiness and it does not dry very quickly. Whereas Cold Size 4 is a liquid solution at room temperature, and dries out very fast in atmospheric condition, leaving only the solid material on the fibre substrate. Thus Cold Size 4 was selected to be used as the right kind of recipe for worsted yarns. Modified starch and PVA however were used for conventional method of sizing of worsted single yarns and the results were compared.

3. 2 Fibre properties

The fibre properties were tested to know their behavior during stretching so that appropriate precautions could be taken during sizing. As is well known during sizing of warp yarn, it is always under tension and a definite amount of stretch is produced. If a material is highly extensible then it may cause slackening of warp sheet as it leaves squeeze nip. The results given in Table 4 show that wool is most extensible among all the fibres used in worsted blends. This clearly reveals that the wool component in the yarns has to be treated in a different manner unlike other spun yarns during sizing. The result also shows that linen is the strongest as well as stiffest fibre. It gives lowest extensibility and the fibre may lead to rupture when extended between two nips with higher stretch.

3. 3 Yarn hairiness

Yarn hairiness is greatly affected by the fibre type and fibre properties. The fibre migration theory during ring spinning holds good in deciding the hairiness of yarns. A yarn spun from coarser fibres is more hairy as compared to one that is spun from finer fibres. It is because of the centrifugal force acting on the fibres during ring spinning, which is directly proportional to the fibre linear density. Again fibres with higher bending rigidity are more prone to protrude out as hairs from the yarn structure as because they are comparatively more difficult to be consolidated into the yarn core. This is the reason why the linen and tassar blended yarns show a higher hairiness value. Weavability of

Table 3 Adhesion force (N) for different size recipes.

Sl. No.	Size Recipe	Cotton	PC	Worsted
1	MODIFIED STARCH	61.51	103.79	11.97
2	COLD SIZE 1	72.79	88.00	7.36
3	COLD SIZE 2	29.72	22.56	15.21
4	COLD SIZE 3	36.40	33.55	1.47
5	COLD SIZE 4	71.51	113.80	13.83
6	PVA	89.47	102.81	19.82

Table 4 Fibre properties.

Fibre Type	Average Diameter (μm)	Average Fibre Denier	Average Length (mm)	Average Bending Rigidity ($cN.cm^2/tex^2$)	Average Initial Modulus (cN/tex)	Average Extensibility %	Average Tenacity (cN/tex)
Wool	20.0	2.7	75	0.00020	497	29.36	14.49
Silk	12.5	1.6	78	0.00065	775	20.54	39.69
Tassar	22.5	3.0	76	0.00075	819	16.86	48.24
Linen	21.5	3.5	78	0.00105	1812	2.48	55.08
Cotton	13.5	1.5	30	0.00056	799	7.3	48.78
Wool/Silk Noil	13.0	1.6	30	0.00052	666	18.96	37.26

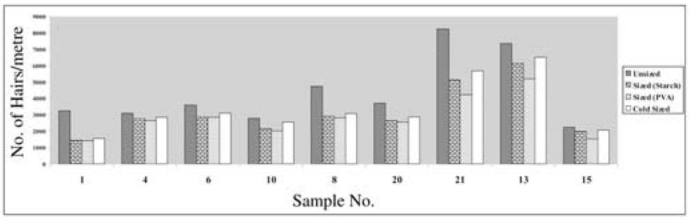

Fig. 3 Hairiness of conventionally sized yarns vs cold sized yarns.

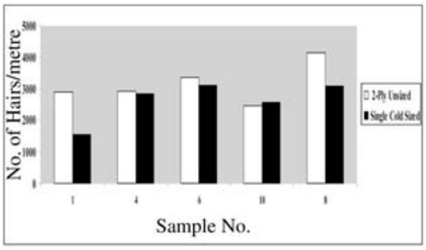

Fig. 4 Hairiness of 2-ply unsized yarn vs single cold sized yarn.

yarns is influenced by the hairiness. So the hairiness was measured using Zweigle hairiness tester. The hairiness of unsized yarns, yarns sized with starch and PVA as well as the cold sized yarns are shown in Fig. 3.

All sized yarns show less hairiness as compared to single unsized yarns. This is because the size material forms a coating/film on the surface of the yarn and thereby laying down the protruding fibres. As is observed from the results, conventional sizing with starch and PVA helps in more reduction of hairiness compared to cold sizing. This is because, add on level in the former case (10–12%) is significantly higher as compared to cold sizing (1–2%). However the difference in hairiness reduction between conventional method and cold sizing method is not significant. A comparison between the hairiness of single cold sized yarn and equivalent 2-ply yarn is shown in Fig. 4. Single cold sized yarns show lower hairiness value as compared to 2-ply unsized yarns. That means a size coating on the yarn surface is more effective in laying down the protruding fibres than consolidating them through the process of twisting/doubling.

3. 4 Yarn extension at breakage

Yarn extensibility largely depends on that of constituent fibres. That is why all wool blend yarns have excellent extensibility. Linen blended yarn shows a poor extensibility, which is well anticipated from the low extensibility of highly crystalline polymeric structure of linen fibres. Wool:silk blends show a low extensibility though wool and silk fibres individually have very high degree of extension. This is because of a strong force of adhesion between wool and silk which probably restricts relative movement between

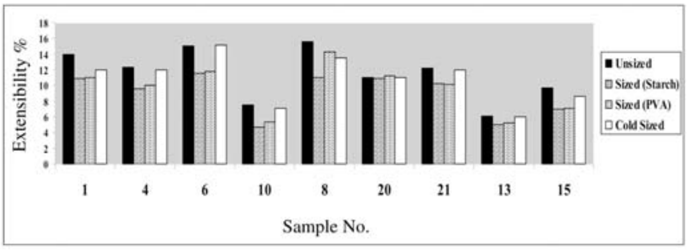

Fig. 5 Extensibility of conventionally sized yarns vs cold sized yarns.

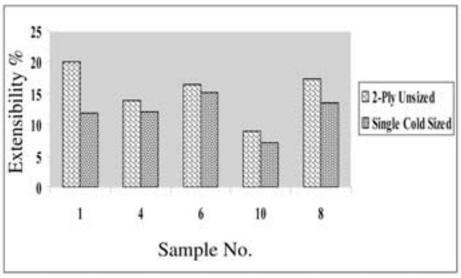

Fig. 6 Extensibility of 2-ply unsized yarn vs single cold sized yarn.

adjacent fibres. Elongation at break has a lot to do in respect of weavability of yarn in terms of facilitating the yarn to withstand the stresses on the loom. The results of yarn extensibility are compared for conventionally sized yarns and cold sized yarns in Fig. 5.

It is a well known fact that all yarns loose extensibility after sizing because the size material binds the fibres together thereby restricting any interfibre relative movement. This fact is supported by the results of conventional sizing as well as cold sizing. However the decrement in extensibility is less, in case of cold sized yarns. This is due to low add on and less penetration of size in case of cold sizing. The extensibility of cold sized yarn was compared with that of 2-ply unsized yarns of equivalent linear density with a view to replace the later which is normally used in the industry despite being very expensive. The results are shown in Fig. 6. All 2-ply yarns have higher elongation at break as compared to their equivalent single cold sized yarns. This is because of the fact that, elongation of plied yarns is contributed by many factors i.e. relative movement between the component yarns, decrimping of individual yarns, decrimping of fibres in the yarn structure and the relative movement of the constituent fibres in the component yarns. Whereas, in the single yarns the first two component factors i.e relative movement of individual yarns and decrimping of the additional twist related waviness are absent. Moreover the size material binds the fibres together, thereby restricting any interfibre slippage. However the difference is not very significant except for 100% wool yarns. The extensibility of wool is well attributed to the crimp in the fibres. This is adversely affected by consolidating the fibres by size application. Plying/twisting also impairs this property but to a lesser extent. Tassar and silk fibres show lower extension compared to wool. Again due to strong cohesion between these fibres in the yarn cross-section, the extensibility is affected. This effect is more prominent in wool:silk blend because of extrafine silk fibres which have a strong adhesion with wool. Yarn extensibility in these cases is less crimp related and is dominated by relative movement between adjacent fibres. This is not much affected by cold sizing with low add on level and less penetration. That is why difference in extensibility between 2-ply yarns and single cold sized yarns is not very wide.

3. 5 Yarn tenacity

Weavability is largely determined by the tensile properties of the yarn as because the majority stresses act along the axial direction of the warp yarns. Thus the tenacity of all unsized and sized yarns was measured on the Instron tensile tester and the results are compared in Fig. 7. It may be observed from the results that after sizing by conventional dip squeeze technique at a temperature of boil of the size solution, the worsted warp yarns loose tenacity in most of the cases. This is attributed to the deterioration of yarn mechanical properties on treatment at a higher temperature. However cold sizing improves tenacity considerably. An increment of tenacity is invariably seen in 100% silk yarns and also in worsted yarns having a cellulosic fibre component. This may be attributed to a higher affinity of starch and PVA towards silk or cellulosic fibres. The

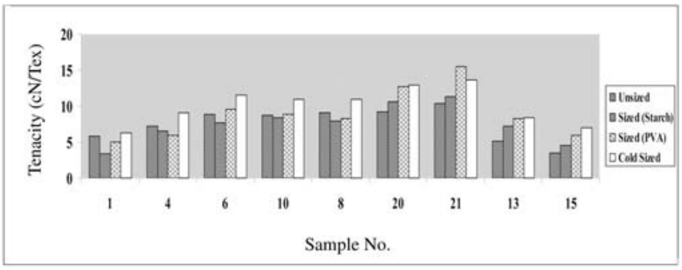

Fig. 7 Tenacity of conventionally sized yarns vs cold sized yarns.

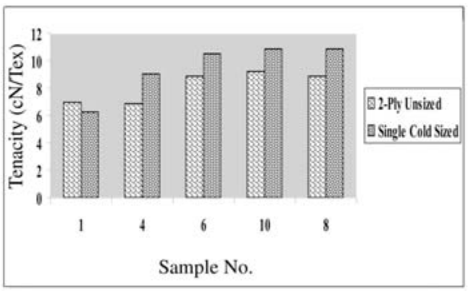

Fig. 8 Tenacity of 2-ply unsized yarn vs single cold sized yarn.

tenacity of single cold sized yarns was compared with that of equivalent 2-ply yarns in Fig. 8.

Single cold sized yarns have higher tenacity as compared to equivalent 2-ply unsized yarns in most cases only except 100% wool yarns. Tassar/mulberry silk blended worsted yarns show more positive results on cold sizing with respect to tenacity. The consolidation of fibres which is better than 100% wool is further enhanced by cold sizing. However cold sizing has not been much effective in case of 100% wool yarns. The reason may be excessive crimp in the wool fibres which makes the yarn more bulky and prevents the size material to consolidate the fibres together. A higher add on by increasing the squeeze pressure slightly may enhance yarn tenacity.

3. 6 Yarn bending rigidity

The yarn bending rigidity depends upon bending rigidity of fibres and the cohesiveness of fibres inside the yarn structure developed by their crimp and the process of twisting. Higher bending rigidity of linen fibres is responsible for a higher value in the yarn. However a substantially higher bending rigidity in case of wool:silk yarn is because of a high degree of cohesiveness between these two kind of fibres. This cohesiveness is because of the stickiness of super fine silk fibres (12.5 micron, 1.6 denier) with the highly crimped wool fibres. Bending rigidity of yarn is the determining factor for flexing performance on the loom. Thus it was felt necessary to study the bending behavior of yarns using the Kawabata pure bending tester (KES FB2). The results for unsized, conventionally sized and cold sized yarns are given in Table 5. It is clear from the results that after sizing the yarns become more rigid because the size material binds the constituent fibres together and fills the interstices/open air space in between them thus restricting the fibre movement or deformation. Bending rigidity is increased after conventional sizing as well as cold

Table 5 Bending rigidity of conventionally sized yarns vs cold sized yarns.

Yarn Count (Tex)	Blend	Blend%	B ($cN.cm^2$/Yarn) Unsized	Sized (Starch)	Sized (PVA)	Cold sized
1/25	Wool	100%	0.00024	0.00044	0.00045	0.00035
1/20	Wool・Tsr	80:20	0.00024	0.00045	0.00036	0.00031
1/20	Wool・Tsr	70:30	0.00025	0.00056	0.00044	0.00039
1/20	Wool・Silk	70:30	0.00088	0.00157	0.00141	0.00124
1/20	Wool・Tsr	60:40	0.00022	0.00051	0.00038	0.00035
1/50	Silk	100%	0.00021	0.00059	0.00044	0.00038
1/83	Silk	100%	0.00118	0.00355	0.00245	0.00245
1/42	Wool・Linen	70:30	0.00063	0.00159	0.00114	0.00099
1/50	Wool・Cotton	65:35	0.00110	0.00345	0.00256	0.00201

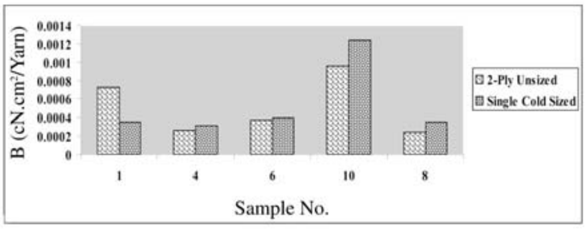

Fig. 9 Bending rigidity of 2-ply unsized yarn vs single cold sized yarn.

sizing. However bending rigidity of cold sized yarns is less than conventionally sized yarns as the add-on is considerably low in the former case. A lower bending rigidity is preferable for better flexing performance during weaving process. The bending rigidity of single cold sized yarns was also compared to 2-ply yarns of similar count in order to ascertain its weavability.

Bending rigidity increases with plying/twisting as well as sizing. It is because plying increases the compactness of yarn while the size material binds the fibres in the yarn cross-section, thereby preventing the fibres from any deformation such as bending. Cold sized single yarns show a higher bending rigidity as compared to 2-ply yarns except in case of 100% wool yarns i.e because of higher crimp in wool fibres which allows for more pliability of yarn. That means for 100% wool yarns, the size add-on can be slightly increased to achieve the desired properties.

3. 7 Weavability of non-conventional worsted yarns

The yarn samples were tested for the abrasion cycles they can withstand before failure, on the weavability tester. The results are shown in Fig. 10.

As is apparent from the results of conventional sizing, the sized yarns rather loose weavability after application of the size. It is because, the properties of wool deteriorate at high temperatures. Weavability of single worsted yarns is adversely affected when sized through conventional technique due to stretch during the process which causes loss of extensibility and the loss of tenacity, when treated at a high temperature. Thus cold sizing appears to be the only

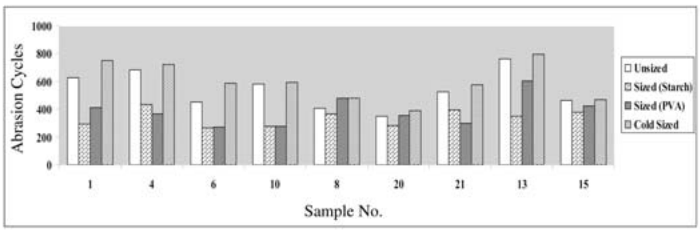

Fig. 10 Weavability of unsized, normal sized and cold sized worsted yarns.

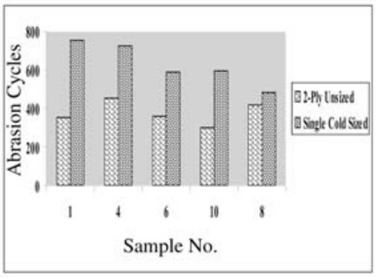

Fig. 11 Weavability of 2-ply unsized vs single cold sized yarns.

option for worsted yarns. The results clearly show that cold sizing at room temperature results significant improvement in weavability. The single cold sized yarns were compared with the equivalent 2-ply unsized yarns for their weavability with a view to explore the possibility of weaving single yarn to facilitate production of light weight fabric and also to replace expensive 2-ply yarn. The result is demonstrated in Fig. 11. It is clearly seen that the single cold sized yarn shows better weavability as compared to equivalent 2-ply unsized yarns. This is achieved because of a strong consolidation of fibres in the yarn cross-section through cold sizing. The higher weavability of single cold sized yarn can also be attributed to improved hairiness and minimal loss in extensibility as examined earlier in sections 3.3.2 and 3.4.2 respectively. From the above results it is expected that single cold sized yarns will perform better than the 2-ply unsized yarns on the loom.

3. 8 Yarn failure mechanism

As well established practice in weaving process control, analysis of broken warps on loom reveals the nature of break. It helps to understand the root cause of yarn failure during weaving. Therefore the yarn failure mechanisms were studied on the weavability tester so as to ascertain whether the yarn breaks because of fibre breakage or inter fibre slippage. The broken yarn ends were analyzed photo micrographically. The photographs given in Fig. 12, 13 and 14 show the failure mechanisms of single unsized yarn, single cold sized yarn and 2-ply unsized yarn respectively.

Normally a warp yarn does not break because of lack of strength during the weaving operation. The strength of yarn in fact is much greater than the average tension imposed on it due to weaving stresses. Rather, the abrasion in between neighboring yarns and with the machine elements is significantly responsible in this regard. As the weaving progresses, this repeated abrasion action loosens yarn structure and as a result some protruding fibres come out from the yarn body and fuzz ball formation takes place on the yarn surface. Removal of one or few fibres from yarn structure creates a void in yarn body which facilitates easy

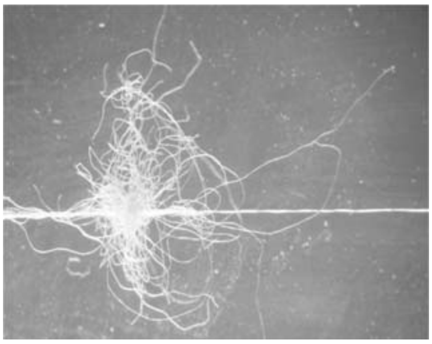

Fig. 12 Failure mechanism of single unsized yarn.

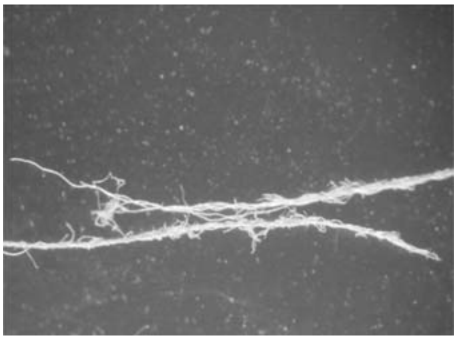

Fig. 13 Failure mechanism of single cold sized yarn.

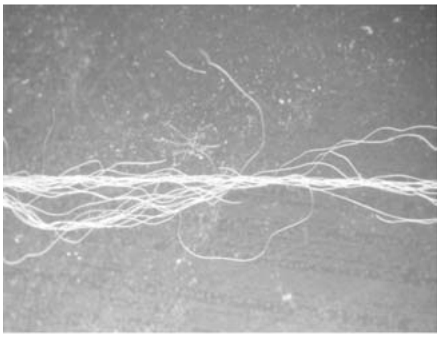

Fig. 14 Failure mechanism of 2-ply unsized yarn.

movement of constituent fibres called interfibre slippage. It is therefore important to apply a sort of protective coating of an adhesive, which lays the protruding fibres on the body of the yarn, thus reducing the friction to the yarn as it passes through the loom parts. This presents a tremendous scope to improve weavability and fabric quality through sizing of single worsted yarns.

It is clearly visible that the single unsized yarn fails because of surface damage and fibre entanglement causing fuzz ball formation on the yarn surface. The fibres accumulating on the surface no longer contribute towards the axial strength as a result of which slippage occurs between the remaining fibres in the cross-section and the yarn fails.

In contrast to the unsized yarns the cold sized yarn does not fibrillate so easily because of fibre consolidation by the adhesivity of size material with fibre substrate. Rather the failure occurs due to fibre breakage. Moreover the fibres in the cross-section of the cold sized yarn act in aggregate and not individually, thus enhancing the mechanical properties. This is the reason behind better performance of cold sized yarn on the weavability tester.

Yarn mechanical properties are considerably improved by plying but ultimately the 2-ply yarn breaks when one of the component yarns fails. Failure occurs basically by fibre slippage because wool fibre has very high extension at breakage and almost no fibre breaks before the yarn fails due to fibrillation and lack of interaction and assistance of neighboring fibres in the cross-section of individual yarns. The structural disintegration in this case is somewhere between the single unsized and cold sized yarn. In the present paper, only the photographs of the sample No.6 have been given as the representative ones.

3. 9 Yarn progressive failure on weavability tester

The study of warp breakage mechanism clearly revealed that interfibre slippage is one of the most predominant factors which induced yarn failure. It is also well known that interfibre slippage is responsible for yarn extension. Therefore it was thought needful to analyze and study the elongation behavior of the yarns with respect to abrasion on the weavability tester. A comparative study was carried out between single unsized, single cold sized and 2-ply unsized yarns of 100% wool, wool:tassar and wool:silk blends. From Fig. 15, it can be inferred that for 100% wool compositions, the 2-ply unsized yarn has a steady elongation behavior on the weavability tester. This is because of twist balance and stability of stresses in the 2-ply yarn which enables it to behave consistently through out the cycle of loading and abrasion on the tester. The single cold sized yarn however has a sigmoid behavior. The initial low elongation zone describes the decrimping of the wool yarn which is of course low due to loss of crimp in the sizing process. Thereafter the yarn shows a very high elongation rate due to decrimping of the fibres in the cross-section which themselves are highly extensible inherently. The final zone of low elongation is because of the restraint generated by the adhesion of size with the fibres which restricts any interfibre slippage. Finally the fibres fail to assist towards the axial resistance to loading and failure starts at the weakest fibre or at the weakest link between the fibre and size. The single unsized yarn shows higher elongation compared to cold sized yarn in the initial zone, because the crimp in the parent yarn is retained and that contributes towards the extension in the beginning. However once the crimp is removed and the stresses are relieved from the yarn it starts behaving consistently till the yarn fails.

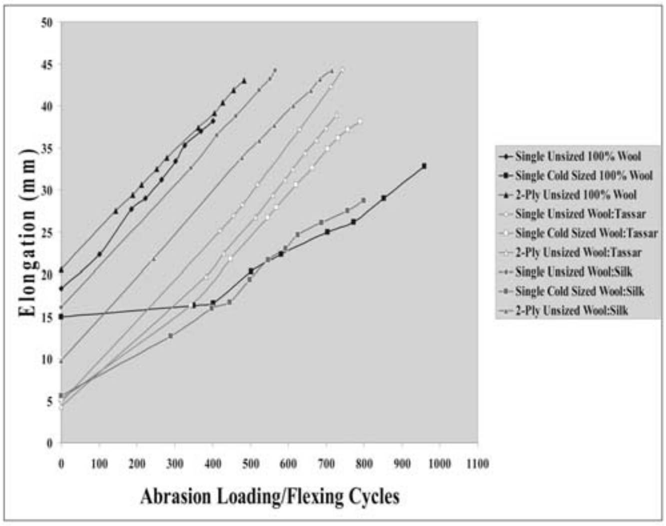

Fig. 15 Abrasion cycles vs elongation of 100% wool, wool:tassar and wool:silk yarns.

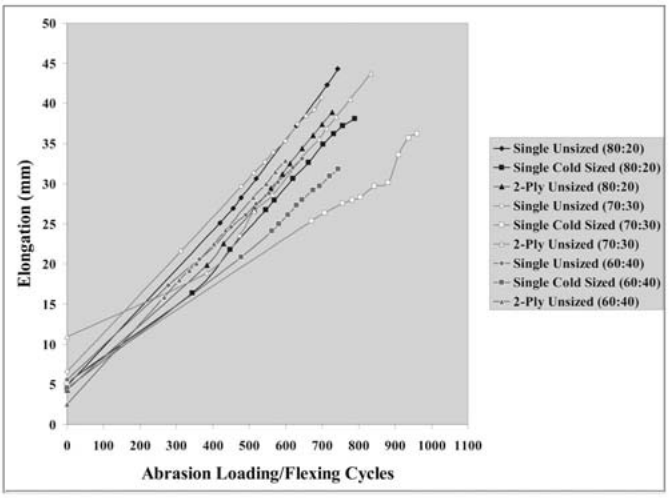

Fig. 16 Abrasion cycles vs elongation of wool:tassar yarns of different blend proportions.

A different behavior is seen when wool is blended with other fibres. However in wool:tassar blends it is mostly dominated by the majority component i.e. wool fibres. All yarns show consistent elongational behavior along the abrasion-loading cycle. Parent single yarn is highly extensible due to crimp retention in the unrelaxed state. Extensibility is restricted by plying as well as sizing, but resistance to abrasion-loading is improved.

Mulberry silk is finer as compared to tassar silk. Thus in wool:mulberry silk blended yarn, a higher number of fibres per cross-section is achieved for the same linear density of the yarn. More uniformity in fibre distribution in the cross-section leads to uniformity in mechanical behavior. This is clearly reflected in all the yarns of wool:mulberry silk combinations. Extensibility is again restricted by twisting and sizing but, mechanical properties are improved.

As is demonstrated in Fig. 16, for wool:tassar (80:20) blend, weavability is mostly dominated by the behavior of the majority component i.e. wool fibres. All yarns show consistent elongational behavior along the abrasion-loading cycle. As the share of the other component fibre i.e. tassar is increased to 30%, there is a shift in the behavior of the yarns. The single yarn now starts behaving consistently due to large number of fibres in the cross-section and the homogenization of structure and properties achieved thereby. The 2-ply yarn shows slight turbulence in behavior due to the fact that the individual component yarns have less number of fibres in the cross-section and can't exhibit the level of uniformity in fibre distribution along the cross-section. Single sized yarn behavior is influenced by the size-fibre interaction. As the percentage of tassar silk component is further increased to 40%, a uniformity of fibre distribution is achieved both in single and equivalent 2-ply yarn. However the cold sized single yarn continues to behave in the usual way.

4. Conclusions

It is observed that cold sizing proves to be suitable for single worsted warp yarns. Cold sizing process reduces yarn hairiness as compared to unsized single and equivalent 2-ply yarns. Reduction in extensibility is less in cold sizing compared to conventional sizing. Tenacity of cold sized yarn is higher than single unsized and 2-ply unsized yarns. Bending rigidity of cold sized yarns is lower compared to conventionally sized yarns. Cold sizing kit integrated with sectional warping machine has been successfully developed and used for preparation of single worsted warp yarn. The cold size mix and the sizing process parameters have been optimized; weaving performance has been found to be quite satisfactory as compared to single unsized yarn and 2-ply yarn of equivalent linear density.

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