Influence of Biopolishing Enzymes on Physical Properties of Cotton Knit Goods

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Apart from polishing the fabrics, the treatment offers a number of other benefits in physical properties such as improvement in pill resistance, cooler fill, brighter luminosity of colors and softness. At the same time, the treatment results in certain adverse effects like loss in weight and strength. All the above effects are influenced by a number of factors like, composition of the acid cellulase, history of pretreatments given to the fabrics and process parameters used at the time of treatment.

Various developments have taken place in the eco-friendly processing of textiles involving enzymes. Among the various enzymes, cellulase is extensively used on cellulosic material. There are two types of cellulase, namely, acid cellulase and neutral cellulase. Acid cellulase used in biopolishing, which is very popular finishing treatment given to cellulosic fabric. Apart from polishing the fabrics, the treatment offers a number of other benefits in physical properties such as improvement in pill resistance, cooler fill, brighter luminosity of colors and softness. At the same time, the treatment results in certain adverse effects like loss in weight and strength. All the above effects are influenced by a number of factors like, composition of the acid cellulase, history of pretreatments given to the fabrics and process parameters used at the time of treatment. Moreover, the treatment has influence on post treatments given to the fabrics.

In the textile industry, especially in the apparel sector, cotton is widely used because of its superior properties and it still holds the name as king of fibres. Cotton blended fabrics faces a major problem i.e. pilling. Pilling is defined as the tendency of fibres to loose from a surface and form balled or matted particles that remain attached to the surface of the fabric. For the consumer, it affects fabric aesthetics and comfort. For the manufacturer, fabric pilling is a headache that affects the appearance and wear-ability of finished apparels. Pilling is a complex phenomenon comprised of multiple stages that progressively accelerate the rate of fibre removal from the yarn structure, thus shortening the life span of garments and other textile properties.

Pilling is particularly problematic for knitted fabrics. At the same time, knitted fabrics have several advantages over woven fabrics, such as higher production rates, lower production costs and softer fabric structures. Still, the pilling problem that results from the slack fabric structure remains a significant objection. Essentially there are a number of methods to reduce pilling in commercial use. One approach is to apply surface active agents, like a polymeric coating that binds fibers to the fabric surface. These are often friction reducing lubricants, such as acrylic copolymers. Shearing and singeing are common methods used to produce a clean, smooth surface on fabrics. Singeing, in particular has the real potential to scorch the fabric surface. The down side of surface active agents includes a reduction in hydrophilicity and the gradual loss of the agent after a few washes, which eventually makes fabrics harsh and fuzzy.

Enzymatic removal of fuzz is carried out under milder conditions and is absolutely safe, efficient and permanent. Cellulase enzymes give fabrics a clear, even surface appearance. They reduce the tendency to pill and improve softness, especially when compared to traditional softeners. Moreover, they accomplish this without polluting the environment. As a result, cellulases are increasingly being applied to textile finishing. They are widely used to remove fibrils and fuzz fibres from cotton fabrics.

Requirements of yarn quality for Woven & Knitted fabric

For woven fabric

Requirement profile of cotton weft yarn
In contrast to earlier considerations, a weft yarn today must have a requirement profile as high as that of a warp yarn in order to satisfy the requirements of high-production weaving machines. According to the scientifically-based investigations carried out by various literatures a weft yarn must exhibit at least the following quality characteristics as indicated in Table 1. It can be concluded from the above that the previously-used 'mean breaking length' for forecasting the running conditions in the weaving mill is no longer sufficient. What have become particularly important, for instance, are the yarn elongation as well as the variations in breaking force and elongation. The Classimat faults can also be considered as weak places, because a thick place fault usually contains less twist than the rest of the yarn, and can easily break when a tensile force is applied. It should be mentioned here that, with a higher variation (i.e., a higher coefficient of variation value of breaking force or elongation), this can only be compensated by a higher breaking force or elongation at break value in order to achieve equivalent running conditions. In terms of the spinning process, this means "Better raw materials, higher yarn twist, etc., certainly result in increased yarn manufacturing costs".

Requirement profile of cotton warp yarn
In contrast to a weft yarn, the cyclic loading of a warp yarn is an important quality characteristic. This is the case with weak places which slip apart due to too little twist, as for instance with a slub-type yarn fault. Furthermore, with warp yarn, hairiness is becoming increasingly important, i.e., there should be little hairiness and it should be evenly distributed. The requirement profile of a cotton warp yarn is indicated in Table 2.

For knitted fabric

Requirement profile of cotton knitting yarn
A knitting yarn (100% cotton) for high-production circular weft knitting should exhibit the quality characteristics as indicated in Table 3.

In contrast to weaving yarns, the yarn strength of knitting yarns is secondary, as the loading placed on the yarn during knitting is lower than that with a high-production weaving machine. However, the yarn must exhibit enough elongation and elasticity. There must be no weak places or thick places that can result in stop holes in the knitted material, or even broken needles. Particularly important is the ability of the yarn to pass easily through the various guide elements of the machine (low friction value). The moisture content of the yarn should be evenly distributed. In most cases, a constant and high hairiness value with a low twist is required in order to achieve a soft fabric handle. However, this hairiness value must remain constant and be without periodic variations, and also be of a level suitable for the type of end product.

Table 1: Requirement profile on cotton weft yarn

Count variation CVt, cut length 100m	<2.0%
Breaking tenacity [Fmax/tex)	> 11 cN/tex
Breaking force variation [CVFmax)	< 10%
Elongation at breaking force [Efmax]	> 5%*
Variation in elongation at breaking force [CVEFmaxl]	<10%
Weak places**	< 1 per 100,000 m
Hairiness H	to be agreed upon between the partners based on the requirements of the weft insertion system and the end product [e.g. < 50% value of the Uster® Statistics]
Hairiness variation between packages H*** Cvb	<7%
Seldom-occurring thick and thin place faults (CLASSIMAT values)	< 50 % value of Uster® Statistics

* 1 % losses in elongation can be compensated by an increase in breaking tenacity of 2 cN/tex
** Definition of a weak place: < 60% of the mean breaking force
*** Variation between packages. Higher values can lead to stripiness with single-colored materials.

Table 2: Requirement profile of cotton warp yarn

Count variation CVt, cut length 100m	<2.0%
Breaking tenacity [Fmax/tex]	> 11 cN/tex
Breaking force variation [CVFmax]	< 10 %
Elongation at breaking force [Efmax]	> 5%*
Variation in elongation at breaking force [CVEFmaxl)	< 10%
Weak places*	< 1/100,000 m
Hairiness H	to be agreed upon between the partners based on the requirements of the weft insertion system and the end product [e.g. < 50% value of the Uster® Statistics)
Hairiness variation between packages H** Cvb	<7%
Thin places/ thick places/neps (CLASSIMAT values)	< 50 % value of Uster® Statistics < 50 % value of Uster® Statistics

* Definition of a weak place :< 60% of the mean breaking forces
** Variation between packages. Higher values can lead to stripiness with single-coloured fabric.

For single jersey materials the yarn evenness and count variations are important parameters. The short, medium and long-term count variations lead to cloudy or stripy fabrics as soon as a certain mass variation level is overstepped. In addition, neps & vegetable matter and high dust content refer to the types of foreign matter that is particularly disturbing. These lead to wear of the needles, holes in the knitted material and, in many cases, to dyeing problems.

Enzymes for Biopolishing

Cellulases are derived from both fungal and bacterial sources. They find extensive application on cellulosic materials and about 1 0% of the finishing of these materials is estimated to be performed by these enzymes to achieve various effects. They also find application in food, pharma and paper industries. Cellulases used in bio-finishing of cellulosic fabrics are derived from more than ten different fungal species which vary in their component composition, application pH and special effects produced. Cellulases derived from the fungus, Trichoderma reesei is widely used in textile finishing since it gives higher yield in industrial production. In addition to cellulases originating from the above fungus, those originating from Humicola insolens can also degrade cotton cellulose efficiently and they find extensive application in biostoning of denim fabric.

Action of cellulases

Cellulases derived from Trichoderma reesei contains a group of enzymes namely, endoglucanases (EG), cellobiohydrolases (CBH) or exoglucanases and Bglucosidases and they act synergistically to hydrolyse cellulose. It has been found that this fungus secretes at least five types of EGs and two types of CBHs. It is estimated that the secreted enzyme constitutes 60% of CBHI and 10% EGI and EGI!. The structures of EG and CBH shown in fig. 1 reveal the presence of cleft in the EG and a tunnel in the CBH. It is reported that due to the presence of tunnel, CBH has a more pronounced effect on the rate of hydrolysis than the EG. Cellulases can be used for biopolishing as derived from their sources or after enriching the EG content in the mixture. The mixture of endoglucanases, exoglucanases and B-glucosidases are called whole cellulases or total cellulases. Using advances in biotechnology new strains are being developed for producing novel cellulase compositions.

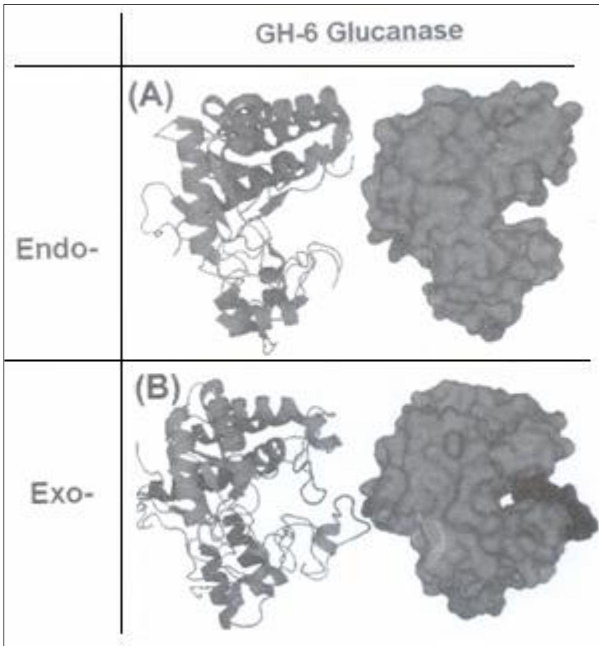

Figure 1: Structure of glucanases

Table 3: Requirement profile of cotton knitting yarn

Count variation CVt, cut length 100m**	< 1.8 %
Count variation CVt, cut length 10m**	<2.5%
Breaking tenacity [Fmax!tex]	> 10 cN/tex
Elongation at breaking force [Efmax]	>5%
Yarn twist(a_m value)	Ring-spun yarn 94-110 (3.1-3.6 am value) /
	Rotor-spun yarn up to 25 % higher than ring-spun yarn
Paraffin waxing/surface friction value	0.15µ
Yarn irregularity**	< 25 % value of Uster® Statistics

Hairiness H***	[e.g. > 50% value of the Uster® Statistics]
Hairiness variation between bobbin H****CVb	<7%
Seldom-occurring thin and thick place faults (CLASSIMAT values)	< A3/ B3/ C2/ D2 or Dl or more sensitive (Cleaning limit)
Remaining yarn faults (CLASSIMAT values)	A3 + B3 + C2 + D2 =< 5/100,000 m

* A low breaking force value must be compensated by a higher elongation at breaking force value ** Highest requirements with single jersey

*** Higher, but constant hairiness as a result of the cloth appearance and handle. The minimum hairiness value must be set based on agreements between the partners

**** Variation between packages. Higher values can lead to 'rings' with single-colored fabrics

The mechanism of cellulase action on cellulose as shown by Fig.2 is as follows: (i) the endoglucanases degrades cellulose by selectively cleaving through the amorphous sites and breaking long polymer chains into shorter chains, (ii) cellobiohydrolases degrades cellulose sequentially from the ends of glucose chains, thus producing cellobiose as the major product and it plays a mediator role in degrading cellulose, and (iii) B-glucosidases complete the hydrolysis reaction by converting cellobiose into glucose.

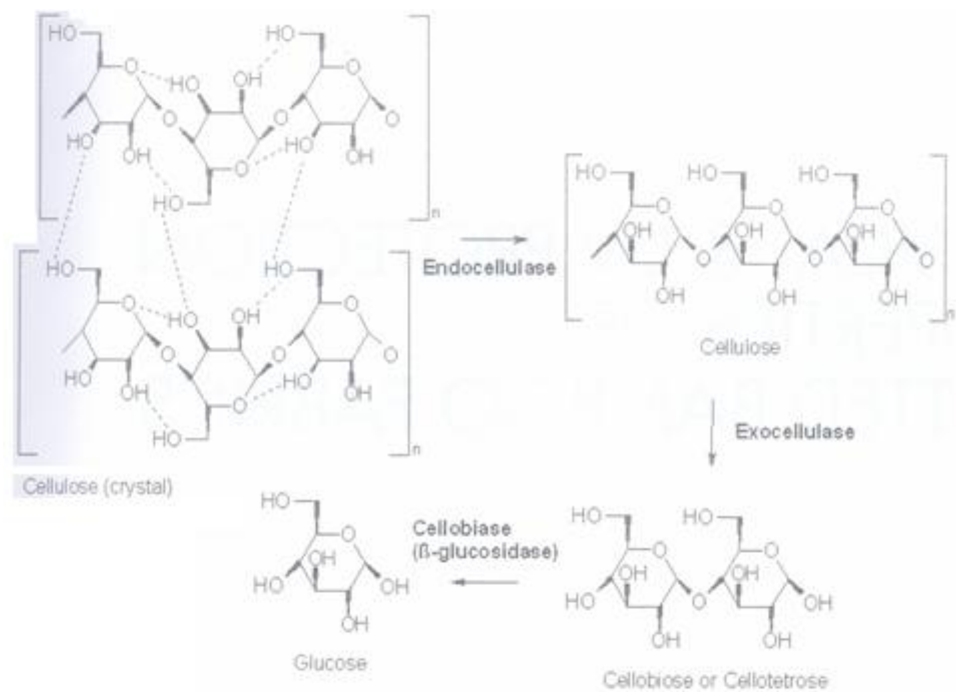

Figure 2: Mechanism of cellulases action on cellulose

Factors affecting hydrolysis due to enzymes

Temperature, pH and time are only part of the process. Other issues include the following:

1. Fiber type and cross sectional shape
2. Yarn type and construction
3. Fabric type and construction
4. Fabric finishes

5. The type of spinning system affects the pilling resistance of fabric. Yarns produced by different kinds of spinning systems have structural differences that impact pilling resistance. Ring spun yarn has real twist and good fiber orientation, while open end yarn has real twist but poor fiber orientation. In both, yarn construction and orientation is different. Commonly, ring spun yarn has approximately 20-40% higher hairiness than open end.
6. Any production process that results in a significant reduction in friction, such as with textile drums, jet or soft flow, etc the result will be a reduction in the pilling effect.
7. Inhibition of enzyme activity can occur and hence the rates of hydrolysis are affected by the presence of disaccharides, glucosidases, and other byproducts.
8. For textile processing, the most important cellulase enzymes are predominantly EG, CBH.

Changes in physical properties due to biopolishing enzymes

Pilling

After the biopolishing of the knitted fabrics it was observed that the pilling resistance ratings of the fabric samples knitted from combed yarn and from open-end yarns were similar to each other, and there was no significant difference between them. The pilling resistance of open-end yarns-based knitted fabrics and combed ringspun yarn-based knitted fabrics were better than the carded ring-spun yarn-based knitted fabrics. When the number of turns of the Martindale Instrument was increased up to 5000t/m, both ring and open-end yarns demonstrated higher pilling values.

Strength

The biopolishing process partly hydrolyses the cotton, which has a negative effect on fabric strength level. Fabrics from combed yarns gave the best strength level. Fabrics from combed yarns gave the best strength values for untreated and enzymatic treated in three different stages, rather than fabrics from carded and open-end yarns. The fabric sample strength loss caused by enzymatic treatment after pre-treatment or dyeing processes is nearly the same in all type of fabrics, approximately around 11 %. In fabric samples enzyme treated twice after pre-treatment together with the dyeing processes, loss in strength is about 25% in average, and the fabric samples from combed yarn exhibit a noticeably higher loss of strength.

Fabric weight

After the biopolishing process, 1-5% loss in fabric weight is occurred. Weight loss of enzymatic treated fabric samples after pre-treatment was slightly higher than for those which were enzymatic-treated after dyeing. The reason for this is the high number of process phases, the high amount of mechanical forces and the long process period, which cause the removal of the fuzzes from the yarn surface. When the weight loss is compared according to the yarn spinning system, the fabric from carded yarn had the highest value while the open-end yarn had the lowest. The amount of weight loss that occurs after the double enzymatic treatment was significantly higher.

Colour change

K/S of enzyme treated carded yarn fabrics appeared higher i.e. darker after enzyme processing, however, K/S value remains unchanged significantly with reference to weight loss for vat dyed fabrics and fabrics dyed after cellulase treatment with direct and reactive dyes. In the case of fabrics pretreated with cellu lases and then dyed, the decrease in the K/S values after laundering less compared to untreated fabrics, especially after 20-30 wash cycles.

Dimensional stability

Hydrolysis of cellulose molecules in different regions of the cotton fibres alters the dimensional stability of the fabrics, which is further influenced by single jersey, interlock and woven structures. EG-rich cellulase treatment of fabrics show lower shrinkage compared to CBH-rich and total crude cellulase. While control sample results about 3% shrinkage, the enzyme treatments result the shrinkage in the range of 0.5% to 1.0%. Dimensional stability further increases with number of washes with EG-rich enzymes compared to total cellulases EG and after 10 washes, the EG-rich enzyme treated fabrics show about 80% less shrinkage, independent of concentrations.

Water Absorbency

Water absorbency and water retention properties of fabrics, after biopolishing are modified with reference to the control fabrics, further controlled by fabric construction parameters and extent of hydrolysis. The cellulase treated fabrics showed higher energy dissipation under wet conditions (heats of sorption), implying that they might offer slightly superior thermal comfort performance under hot and humid conditions. Water retention capacity of cotton and cotton/linen increases by 24-28% due to splitting of micro fibrils and surface peeling effects. As the enzyme hydrolysis removes accessible amorphous portions in different reasons during hydrolysis, the adsorption of moisture decreases with treatment time. Wettability of the fabrics after biopolishing reduces from 4.52 seconds to 0.78 seconds for medium weight and from 20.1 to 12.9 seconds for heavy weight fabric, which further decreases in the case of combined enzyme and softener treatment.

Conclusion

Biopolishing of cotton fabrics with cellulase enzyme results in both beneficial and adverse effects. By suitably optimizing the process conditions, the strength loss during the process can be aimed to a required level, without compromising other handle properties.

This article was originally published in the Textile Review magazine, October, 2012, published by Saket Projects Limited, Ahmedabad.