ACCELERATED DIMENSIONAL STABILITY TEST METHOD DESIGNED FOR 100% COTTON SINGLE JERSEY WEFT KNIT FABRIC IN URGENT SITUATIONS

Dunstan Weragala

148335G

Degree of Master of Science /Master of Textile and Clothing Management

Department of Textile and Clothing Technology

University of Moratuwa

Sri Lanka

May 2017

ACCELERATED DIMENSIONAL STABILITY TEST METHOD DESIGNED FOR 100% COTTON SINGLE JERSEY WEFT KNIT FABRIC IN URGENT SITUATIONS

Dunstan Weragala

148335G

Dissertation submitted in partial fulfillment of the requirements for the degree Master of Science/ Master of Textile and Clothing Management

Department of Textile and Clothing Technology

University of Moratuwa
Sri Lanka

May 2017

DECLARATION

"I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my dissertation in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Name of Student : Dunstan Weragala

Registration No. : 148335G

Signature : Date:

The above candidate has carried out research for the Masters Dissertation under my supervision.

Name of the Supervisor: Eng. S.N. Niles.

Signature of the supervisor: Date:

ABSTRACT

Standard dimensional stability test methods have higher lead times. In a manufacturing environment a dimensional stability test method with shorter lead time is an option provided under some international standards. Such test methods have been developed based on one specific machine designed exclusively for this purpose. As a solution, an alternative test procedure was developed in an existing washing machine for industrial use.

The Miele automatic front loading washing machine was selected for this research. A washing and drying procedure developed with 30-minute washing procedure and 30-minute tumble drying procedure. This research related only to 100% cotton single jersey products. The key features of the BS EN ISO 6330:2012 washing and drying procedure was compared with those of the proposed washing and drying procedure.

A pilot run with five samples was done with three different weights against proposed washing and drying procedure for conditioned, unconditioned states and BS EN ISO 6330:2012 washing and drying procedure. Thirty samples were tested in one material to confirm the consistency of the new washing and drying procedure. Twelve samples representing four different GSM values were tested according to BS EN ISO 6330:2012 and proposed washing and drying procedure and a satisfactory correlation was obtained.

DEDICATION

I lovingly dedicate this dissertation to my parents, wife and two sons, who supported and encouraged me in every way during my studies.

ACKNOWLEDGEMENT

I would like to express my deepest appreciation to all those who provided me with the guidance and assistance to complete this project successfully.

My special gratitude goes to my project supervisor Eng. S. N. Niles for his exemplary guidance, monitoring, encouragement and instruction for the project. I would also like to extend my gratitude to our project coordinator Dr. Sanath Jayawardena for his support and coordination and to the panel of lecturers for their mid reviews of the project which help me to follow the correct direction.

I appreciate the support rendered by the managing director of Hayleys Fabric PLC, Mr Rohan Goonetilleke by permitting me to carry out this project at Hayleys Fabric PLC. My special thanks also go to Mr Ajith Senarathna for his technical advice and for sharing his knowledge and experience throughout my project. I would like to extend my sincere thanks to my physical testing lab team for their generous support. Special thanks to Milinda Tennakoon, Saliya Bandara, Manoj Mahanama, Chandana Yapa,Priyantha Sanjeewa and Asantha Basnagoda who supported me whenever I needed the assistance.

Finally, I would like to take this opportunity to thank our lecturers, non-academic staff and those not mentioned above for their help. And also thanks to the University of Moratuwa administration for providing us with valuable opportunities to enhance our knowledge, skills and attitudes.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

Figures

Tables

LIST OF ABBREVIATIONS AND ANNEXURE

Abbreviations

AATCC	American Association of Textile Chemists and Colorists.
BS	British Standard
cV%	Coefficient of variation
EN	European Norm
ISO	International Organization for Standardization
M&S	Marks & Spencer
RPM	Revolutions per minute
$5N^{h}$	50 °C Normal washing procedure in BS EN ISO 6330:2012
GSM	Grams per square meter
CPI	Courses per inch
WPI	Wales per inch
TPI	Twist per inch
μ	Mean
σ	Standard deviation

Annexure

1 INTRODUCTION

Weft knitted fabric is widely used in the textile industry. It is well known that knitted fabrics such as single jersey fabrics tend to undergo high dimensional changes after washing. Therefore buyers, manufactures, retailers and customers find it necessary to pay special attention to properties related to dimensional stability after washing and drying, mainly when working with knitted fabric. In general, loop-based structures have a greater tendency to create dimensional changes after washing than interlaced structures. 100% cotton single jersey fabric, in particular, is known to give rise to many dimensional stability concerns after washing. We may consider good dimensional stability as one of the primary quality requirements in weft knitted fabrics. International standards such as those defined by BSI, ASTM, AATCC and ISO define washing and drying procedures for textile testing. Apart from these standards, some buyers use their own testing standards and some are based on one of the standards put out by one of the above bodies, usually either the ISO or AATCC test standards, e.g. Limited Brands, George, M&S, Decathlon, etc.

This research was conducted at Hayleys Fabric PLC. It was identified that more than 95% of 100% cotton production was tested according to the BS EN ISO 6330:2012 test standard. Considering the country classification of apparel exports, there is a high demand for Sri Lankan apparels in European countries. Thus, the BSEN ISO 6330:2012 test method selected as the reference test method as it will be useful for factories like Hayleys Fabric, who do the majority of 100% cotton production for the European market.

To complete one test under the standard test method BSEN ISO 6330:2012 will take approximately 10.5 hours. When considering sample preparation and handling time, the total test cycle will be approximately 11 hours, with eight hours for sample conditioning before wash and after wash states. At each stage a minimum of four hours for conditioning is required. In today's competitive environment, customers expect very short lead times for their orders. Therefore manufactures need to review their operation and seek for improvements which result in the saving of time and cost. Fabric manufacturing Fabric manufacturing is an integrated process, primarily containing knitting, dyeing, finishing and quality assurance, where some quality

parameters are directly linked to the performance of individual departments. Washing shrinkage matters mostly in the fabric finishing department. Hence they are very keen on shrinkage/growth matters after washing.

From the finisher's point of view, faster test result feedback is required for their production samples. However, they have to wait at least eleven hours to get dimensional stability test results under the current standard test methods. The situation worsens when the finisher finds the sample has not achieved the acceptable shrinkage range even after eleven hours waiting time. It could create machine capacity allocation issues, losing machine colour run allocation (machine colour run here refers to darkest colour to lightest or lightest colour to darkest, fabric fed in to the machine according to the production plan), less opportunity to go for additional trials, delivery lead time issues, etc.

Higher mechanical tensions applied to a fabric during manufacturing or technically incorrect fabric can create excessive shrinkage/stretch which might not be influenced significantly by the environmental conditions compared to the tensions already applied during the fabric process, for example, in regard to width, the fabric finishes 10cm wider than the original specification. However, in order to understand those significant changes the finisher needs to wait eleven hours in the standard process along with eight hours sample conditioning time. People in production are keen to get their trial and experiment test results within one or two hours. It will benefit them to take immediate action rather than waiting for a long time duration such as eleven hours.

The fabric inspection process involves a great deal of manual handling and time consuming activities. In the inspection process some batches are rejected due to out-of- tolerance wash stability even after it is fully packed, labelled and confirmed for delivery. One lot of fabric contains 30 to 40 rolls. It can be inspected in less than eleven hours. After eleven hours if it is rejected for poor dimensional stability, it will be a huge loss to the inspection capacity. Then the effort involved in this activity will become useless. The inspection team too expects a quick response to the dimensional stability wash test to get the green light to proceed with their activity.

In this research the BSEN ISO 6330:2012 test method is referred as the standard test method and this research was designed to develop a test method for industrial use during fabric manufacturing. A standard test method is always respected as the ultimate requirement for the customer. This option is only recommended to get quick feedback for trials and for finished fabric batches in urgent situations whereby production departments reap many benefits.

1.1 Objectives

1. To develop a wash program cycle and tumble dry cycle which can be completed within 60 minutes.
2. To develop a test method based on the ISO textile test standard structure.
3. To compare the newly developed and conventional testing method practiced in the industry(in terms of their respective shrinkages)

1.2 Significance of the study

It is clear that fabric manufacturers need quick feedback about dimensional stability in certain practical situations. Alternative accelerated test methods provided by the international standards are expensive. For an example AATCC Test Method 187-2013,ISO 23231:2008,M&S P1D-2001 all 3 standards depending on one unique machine called Quickwash Plus™ from SDL Atlas. Investing on Quick Wash plus required more than £ 15,000.00. Developing a test method based on available resources will cut down the investment cost. Such an accelerated dimensional stability test method is a very useful solution for testing laboratories that are regularly demanded urgent feedback from their production departments.

1.3 Scope of the study

This research investigates the dimensional stability to washing and tumble drying of 100% cotton single jersey weft knit fabric spanning a weight range of 120 to 150 GSM.(Initial evaluations of Study1 and Study2 weight ranged up to 160 GSM however with respect to all five studies the GSM range spanning the weight range of 120 to 150 GSM). Its application is as an accelerated test for use in a production environment. The procedure uses a front loading washing machine and tumble dryer with a programmable setting that gives a linear relationship to BS EN ISO 6330:2012.

2 LITERATURE REVIEW

Cotton fiber remains the most important textile fiber in the world. It has excellent characteristics of comfort. However knit fabrics produced in cotton have a high degree of dimensional instability(de Souza, Cherem, & Souza, 2010). Knitted fabrics tend to change dimensions in width and length after being taken off the machine, even without yarn shrinkage, indicating a change of loop shape rather than of loop length(J Spencer, 2001).Similarly S.C. Anand claims in the research that dimensional changes occur due to washing and drying indicated, that the stitch length and yarn linear density of the fabrics examined did not alter significantly upon repeated laundering. This therefore confirms that any dimensional changes that occurred during the washing and drying treatments must have been caused due to changes in loop shape rather than yarn or loop length shrinkage(Anand et al., 2002). As the fabric wets out without tension, swelling of the fibers and subsequently the yarns and the fabric results. Upon swelling, the crimp in the yarn loops increases. In effect, the loops in the knitted structure try to assume their lowest energy state that is a more round configuration, which is the lowest energy state for the yarn and therefore for the fabric(Cotton Incorporated, 2004).Shrinkage and the cause of shrinkage can be further defined or broken down into two different types. That is construction shrinkage and processing shrinkage. This means that shrinkage is affected by the construction parameters of the fabric, and it is also affected by the forces applied in processing in the dyeing and finishing departments as well as the apparel manufacturing facility(Cotton Incorporated, 2004).

Anand and his team from Bolton Institute, UK, researched the effects of washing in three 100% cotton knitted fabrics, plain single-jersey, lacoste and interlock. The results confirmed that the agitation during tumble-drying was the major contributor to changes within the fabrics, causing 34% of the changes observed. This was followed by the spin cycle causing 24% of the changes. Agitation was involved in the rinse cycle contributed to 15% and the wash cycle also caused 15% of the changes(Anand et al., 2002).

Drying Cycle: Mikučionienė has studied the influence of drying conditions on dimensional stability of cotton weft knitted fabrics with six different drying conditions;

1. Hung on a line in course and wale directions,
2. Spread on a smooth surface
3. Winded by hot air
4. Spread on a heated surface
5. Tumble-dryer

The results demonstrate that in all cases the shrinkage values of fabrics, dried in a tumbler-dryer are the greatest. It means that in a tumbler-dryer knitted fabric has the best conditions to shrink in a free state (Mikučionienė & Laureckienė, 2009).Drying conditions are also defined in BS EN ISO 6330:2012 standard washing and drying procedures. Those are;

1. Line dry
2. Drip line dry
3. Flat dry,
4. Flat press tumble dry

(BS EN ISO 6330:2012 - Textiles. domestic washing and drying procedures for textile testing, 2012). With reference to the BS EN ISO 6330:2012 test standard, most of the reputed retail brands recommend to follow the tumble drying method for single jersey 100% cotton fabric sample drying ("George performance standards," 2012),("Tesco textile performance standards," 2012).

Spinning Cycle: 24% of the changes are contributed by agitation of spinning cycle(Anand et al., 2002).

Washing Cycle: "Agitation of the knitted structure whilst it is freely immersed in water appears to provide the most suitable conditions for relaxation to take place as it tends to overcome the frictional restraints imposed by the intermeshing of the structure"(J Spencer, 2001). Further by introducing a detergent to its washing cycle S.C Anand and his team state in their research that detergent caused higher length shrinkage in the fabric than with water alone."(Anand et al., 2002).Similarly (Malik,

Malik, Hussain, & Ramzan, 2013), in their research on the effect of sewing parameters and wash type on the dimensional stability of knitted garments, claim that when comparing wash types - detergent wash and water wash; analysis of the data shows that the wash type is highly significant, with respect to dimensional stability. Research conducted by AATCC research center to compare the 1993 AATCC standard reference detergent and AATCC standard reference detergent 124,found that no significant differences were found in the results using either detergent("AATCC Test Method 135," 2014).For standard test methods AATCC 187:2014 and ISO 23231:2008 in accelerated machine methods, the addition of detergent is not necessary. This is due to the nature of the action of the accelerated test procedure, even a slight amount of detergent foams and impedes the test("AATCC Test Method 187," 2013),(ISO 23231:2008(E), 2008).

Rinse Cycle : AATCC 187:2013 clause no 9.1 states that if the program does not generate satisfactory correlation with dimensional change results from the selected end use test procedure; program elements such as number of rinses and drying time can be altered ("AATCC Test Method 187," 2013).

In addition to the above key factors contributed in a wash, spin, rinse and drying conditions, manufacturers should understand the factors affecting variability in customer washing processes (Munshi, Raje, Ukidve, & Pai, 1993);

1. No two persons wash identical
2. Different detergents are invariably used
3. No two localities have identical water
4. Water temperature often varies
5. No two washing machines are identical
6. No two loads are the same

Birkett highlighted during the starfish project "up to about five cycles, there are relatively large differences between different fabrics; beyond five cycles the changes in dimensions are small and for most practical purposes can be ignored"(Birkett, 1986).BS EN ISO 6330:2012 standard procedure does not require multiple washes.

However three or agreed number of wash and dry cycles are required in AATCC 135-2014 (“AATCC Test Method 135,” 2014).

To fulfill the requirement of the accelerated test method, both most recognized international standards (ISO, AATCC) and buyer (M&S) standard already defined three separate test standards (“AATCC Test Method 187,” 2013),(ISO 23231:2008(E), 2008),(P1D, 2001). All three standards depend on one unique machine called Quickwash Plus™ from SDL Atlas. The Quickwash system is a compact, robust tabletop device that resembles a miniature top loading washing machine. The chambered basket is driven by a shaft that provides high speed agitation during the wash, rinse and extraction sequences. Following the extraction sequence, the samples are subjected to a controlled flow of heated air which induces a tumbling action. (“QuickWash Plus®,” 2007).

According to BS EN ISO 6330:2012 standard wash program $5N^{h}$ testing lead time contains eight hours conditioning time. As described in the standard procedure ISO 139:2005(E) (ISO 139:2005(E)-Textiles-Standard atmospheres for conditioning and testing, 2005) and approximately 2.5 hours washing and tumble drying time(BS EN ISO 6330:2012 - Textiles. domestic washing and drying procedures for textile testing, 2012). In AATCC 135:2014 the standard referred to dimensional stability also contains eight hours conditioning time with minimum three washing cycles and three tumble drying cycles running approximately 4.5 hours (“AATCC Test Method 135,” 2014). However standard accelerated dimensional stability test methods clearly mentioned “The use of standard textile conditioning prior to or after test cycle program completion is not required”(“AATCC Test Method 187,” 2013),(ISO 23231:2008(E), 2008)

Approximately 75% of the total washing and drying cycle lead time covers with sample conditioning to condition samples before wash and after wash stages. Standard washing procedure lead times are highly effected by the sample conditioning with controlled temperature and relative humidity requirements. Reliable accelerated dimensional stability test method is required as a solution for practical situations during the fabric manufacturing at a minimum cost or investment.

3 METHODOLOGY

3.1 Research plan

A new washing and drying procedure is to be defined and that could be completed within 60 minutes. The research was planned with five separate studies related to the proposed washing and drying procedure, the identification of which is discussed later in this chapter.

The following steps were planned in carrying out the research:

1. Carrying out trials to finalize the proposed test procedure parameters.

2. Identify the optimum hydro extraction speed (RPM)

3. Using a particular GSM of a single jersey fabric, compare the dimensional changes after washing with and without conditioning, and according to BS EN ISO 6330:2012 washing and drying procedure.

4. Test the shrinkage values over five washes comparing the proposed and standard methods.

5. Review the test procedure with fabrics of varying GSM values

6. Statistically analyze results to see if there is any relationship between the proposed and standard methods.

Details of the above steps of the plan are given below:

Study 1- Proposed wash program trial run: To review the performance of the defined washing and drying procedure, 100% cotton single jersey fabric samples selected in three different GSM categories namely 120 GSM, 145GSM, 160 GSM were washed and tumble dried as a trial according to the proposed washing and drying procedure and BS EN ISO 6330:2012 washing and drying procedure. Test results were evaluated to finalize the proposed test procedure parameters and their actual time durations.

Study 2- Hydro extraction RPM : The hydro extraction speed (RPM) of the proposed test method was adjusted to different values starting from rpm 400, 500, up to 1000 and the relationship between hydro extraction RPM and the length and width shrinkage was reviewed. These findings were used to finalize the optimum RPM setting for hydro extraction in the proposed washing and drying procedure. 120 GSM, 145 GSM & 160 GSM 100% cotton single jersey fabric were used for this experiment. More details of the materials can be found in the section 3.2. Thereafter, the finalized wash program was implemented to the study 3 research experiment which is about the performance of new washing and drying procedure.

Study 3-Performance of the new procedure: Once the wash procedure was finalized, 100% cotton single jersey fabric samples obtain from 150 GSM fabric material were tested using 30 specimens with 30 washing and drying cycles one by one. Study 3 material details are specified in section 3.2. Then, format as shown in table 1 was filled for the final analysis which shows the test results of the proposed test procedure without fabric sample conditioning and with sample conditioning in the standard atmospheric conditions defined in ISO 139:2005 procedure along with BSEN ISO6330:2012 washing and drying procedure.

Table 1: Proposed test procedure performance table

Sample no.	**Without Conditioning**		**With Conditioning**		**BS EN ISO6330 :2012 5N**	
	Length Shrinkage	**Width Shrinkage%**	**Length Shrinkage%**	**Width Shrinkage%**	**Length Shrinkage%**	**Width Shrinkage%**
1						
2						
3						

Based on table1, statistical data analysis was conducted as explained in section 3.6.

Study 4-Five washes trial: The same 100% cotton single jersey fabric material used in study3 was tested for five washes and five dry cycles according to the proposed test procedure and the performance reviewed along with the samples washed five times according to BS EN ISO 6330:2012 test procedure.

Study 5-Relationship between two procedures : Finally the proposed test procedure was reviewed with washing and drying, 100% cotton single jersey fabric samples representing 120 GSM,130 GSM,140 GSM & 150 GSM(Refer material details in section 3.2) along with standard washing and drying procedure BS EN ISO 6330:2012. The results were statistically analyzed to identify if there was any relationship between the results of the proposed testing procedure those of samples tested according to BS EN ISO 6330:2012 washing and drying procedure.

Finally a new test method based on the ISO textile test standard structure was developed and presented.

3.2 Materials used

Table 2 shows material details of five studies planned for this research. All of these single jersey fabrics consist with 100% cotton ring spun yarn.

Table 2: Fabric material details of study1 to study5

Study No	GSM	Fabric Construction	Yarn Composition	Yarn Count	CPI	WPI	Stitch length	TPI
Study1	120	Single Jersey	100% Cotton	1/40 Ne	59	44	2.54	22.1
	145	Single Jersey	100% Cotton	1/30 Ne	53	37	2.85	19.5
	145	Single Jersey	100% Cotton	1/30 Ne	53	37	2.85	19.5
	160	Single Jersey	100% Cotton	1/40 Ne	59	44	2.54	22.1
	160	Single Jersey	100% Cotton	1/26 Ne	50	36	2.83	18.1
Study2	120	Single Jersey	100% Cotton	1/40 Ne	50	36	2.83	18.1
	145	Single Jersey	100% Cotton	1/30 Ne	53	37	2.85	19.5
	160	Single Jersey	100% Cotton	1/40 Ne	59	44	2.54	22.1
Study3	150	Single Jersey	100% Cotton	1/30 Ne	53	38	2.73	19.5
Study4	150	Single Jersey	100% Cotton	1/30 Ne	53	38	2.73	19.5
	150	Single Jersey	100% Cotton	1/30 Ne	53	38	2.73	19.5
Study5	120	Single Jersey	100% Cotton	1/40 Ne	59	44	2.54	22.1
	130	Single Jersey	100% Cotton	1/30 Ne	44	36	2.96	19.5
	140	Single Jersey	100% Cotton	1/30 Ne	47	38	2.81	19.5
	150	Single Jersey	100% Cotton	1/30 Ne	53	38	2.73	19.5

3.3 Equipment used

In BS EN ISO 6330:2012 washing and drying procedure, annex A refers to specification for washing machine type A. Rotating in a horizontal axis and front loading complying with the specifications of FOM 71 CLS washer and extractor from supplier brand SDL atlas. Figure1 shows FOM CLS 71 washer and extractor.

Figure 1: FOM 71 CLS

Figure 2 shows Miele Professional PW 6055 Vario washing machine. Priority was given for the selection of the washing machine on this research for available front loading washing machines in the testing laboratory at Hayleys Fabric PLC. FOM CLS 71 machine and Miele Professional PW 6055 Vario were front loading machines available to define such an alternative wash programs.

After reviewing operational flexibility, it was decided to use Miele Professional PW 6055 Vario machine for the proposed washing procedure development in this research.FOM CLS 71 machine used to run BS EN ISO 6330:2012 standard washing and dry procedure simultaneously with the proposed washing and drying procedure in the Miele Professional PW 6055 Vario machine. It saved lot of time than doing the BS EN ISO 6330:2012 standard wash and drying procedure and proposed washing and drying procedure in the same machine FOM CLS 71.

Figure 2: Miele professional PW 6055 Vario

To perform tumble drying according to BS EN ISO 6330:2012 washing and drying procedure, annex G referred for the specification for tumble dryers. There, type A1 complying with the specification of SDL Atlas precision tumble dryer model M 223/2. Figure 3 shows precision tumble dryer SDL Atlas -M 223/2. This precision tumble dryer was used to tumble dry all the fabric samples washed according to BS

EN 6330:2012 washing and drying procedure as well as the proposed washing and drying procedure.

Figure 3: Precision tumble dryer (M 223/2) SDL Atlas

3.4 Wash and drying program

The proposed washing and drying procedure needs to comply with basic elements in BS EN ISO 6330:2012 such as the main wash, rinsing, hydro extraction and drying conditions. Table 3 below shows the parameter comparison between proposed washing and drying procedure and BS EN ISO 6330:2012 washing and drying procedure.

Table 3: Washing & drying parameter comparison

Washing & Drying Conditions	BS EN ISO 6330 :2012	Proposed Method	Remarks/Reasons
Washing Temperature	50°C	60°C	To increase the severity
Main Wash Cycle	15min	10 to 15 mins	
Rinse Cycles & Duration	4 Cycles 10 mins	1 Cycle 10 mins	cut of water filling cycle time
Hydro Extraction (RPM)	5 mins RPM 500	2 to 5 mins RPM 1000	Higher RPM hydro extraction remove high moisture content
Total Washing Cycle	1hour 10 mins	20 to 30 mins	
Total Tumble Dry Cycle	1 hour 10 mins	30 mins	ISO 6330 Type I , 100% Cotton Ballast
Tumble dryer exhaust temperature setting	Not exceeding 80 °C for normal fabric and 60°C for delicate fabric	75°C	Should be than 80 °C for normal fabric.BS EN ISO 6330:2012
Total Time Washing & Drying	2 hours and 20 mins	1 hour	

Selection of standard washing and drying procedure from BS EN ISO 6330:2012 is based on the washing temperature and agitation during, heating, washing and rinsing which was categorized as normal, gentle and mild categories. Leading retailer brands such as George and F&F (Tesco) have recommended 50°C wash temperature and

agitation during heating, washing and rinsing in normal condition, for 100% cotton single jersey fabric.

Therefore in this research the BS EN ISO 6330:2012 wash program ran at 50°C normal condition and the selected washing procedure was from Table B1,for Type A machine, procedure number $5N^h$(BS EN ISO 6330:2012 - Textiles. domestic washing and drying procedures for textile testing, 2012).

Apart from the above table 3 parameters, some additional information required to complete the above washing and drying procedure are given below in table 4.

Table 4: Additional information for washing & drying parameter comparison

Washing & Drying Conditions	BS EN ISO 6330 :2012	Proposed Method	Remarks/Reasons
Washing Detergent	ECE Ref98, Sodium Perborate, TEAD	Persil 10g	Avoid to use top loading washing detergent
Test Specimen Size	50cm X 50cm	30 cm X 30 cm	Reduce sample size, faster tumble drying
Water added to dry load (Main Wash)	16 L	7 L	Less water consumption
Wash Load	2 ± 0.1kg	2 ± 0.1kg	Follows the standard
Tumble Dry Load (when samples are dried)	2 ± 0.1kg	1 ± 0.05kg	Reduce tumble drying cycle time

The tumble drying lead-time was expected to be approximately 30 minutes for the proposed washing and drying procedure. To determine the time setting for the tumble dryer for the proposed washing and drying procedure, the timer setting calculation method described in BS EN ISO 6330:2012 Annex P was followed. The tumble dryer exhaust temperature was set as 75 °C.(BS EN ISO 6330:2012 standard recommended to run tumble dry exhaust temperature at minimum 40 °C not exceeding 80°C for normal fabrics)

3.5 Sample preparation

Test specimens for the proposed washing and drying procedure: basic preparation same as AATCC 135:2014 except that the sample size and benchmark distances changed as 30cm X 30cm and 20cm X 20cm respectively. Figure 4 shows the method of marking the benchmarks and method of drawing three test specimens. As

per standard practice it fabric within 50mm of the selvage was avoided and care was taken to ensure that no two fabric contained the same set of wales and weft yarns.

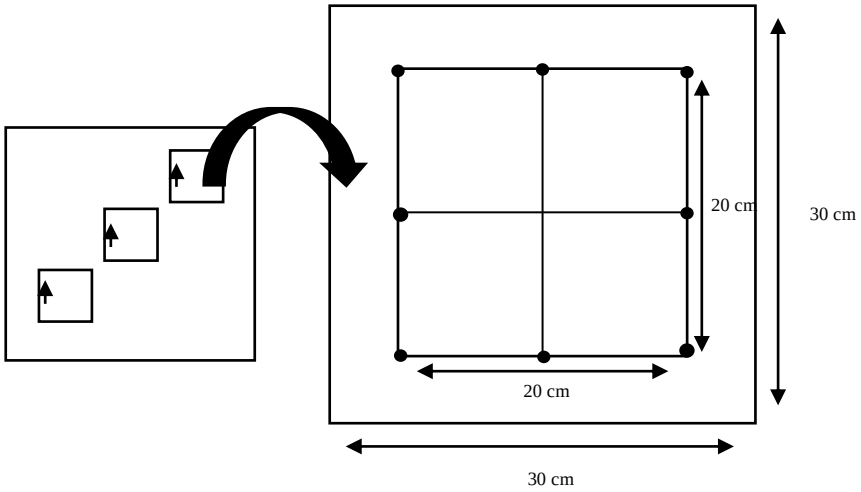

Figure 4: Test specimen size and drawing method

3.6 Testing and data analyzing procedures

Study1-Graphical representation of the test results taken from proposed washing and drying procedure and BS EN ISO 6330:2012 washing and drying procedure to be reviewed for proposed test procedure parameters and for their actual time durations.

Study 2- Graphical representation of the test results. Then the relationship between hydro extraction RPM and length and width shrinkage was reviewed. These findings finalized the optimum RPM setting for the hydro extraction in the proposed washing and drying procedure.

Study3- Graphical representation of the test results of proposed test procedure without fabric sample conditioning and with fabric sample conditioning in the standard atmospheric conditions defined in ISO 139:2005 procedure along with BSEN ISO6330:2012 washing and drying procedure. At each stage ; without sample conditioning, with sample conditioning and BS EN ISO 6330:2012, length and width shrinkages mean value, standard deviation and coefficient of variation percentages were calculated.

Study 4- Graphical representation of the test results according to the proposed test procedure where samples washed and dried five times and the performance along

with sample washed five times according to BS EN ISO 6330:2012 test procedure. Length, width and area shrinkage of the samples reviewed in this experiment.

Study 5- If the proposed washing and drying procedure length shrinkage was denoted by x and BS EN ISO 6330:2012 washing and drying procedure length shrinkage by y, and a straight-line relation. $y = \alpha + \beta x$ was assumed. Such a straight line is generally called a regression line, where y is the response variable (or dependent variable) and x is the explanatory variable (or independent variable). Also, α is a constant, and β is called the regression coefficient. Estimate the constants α and β using the method of Least Squares. If the variables x and y are not related at all and that they have no relation or have nonlinear relation, then, the fitted straight line, $y = \alpha + \beta x$ may not be suitable. That is, the points may appear to suggest that x and y are related though, in fact they are not. Therefore, there could be a need for testing the hypothesis as $\beta = 0$. This hypothesis can be tested using the analysis of variance technique. Same way the linear relationship and the significance between width shrinkages of proposed washing and drying procedure and BS EN ISO 6330:2012 washing and drying procedure was identified.

Note: Proposed washing and drying procedure will be identified as “Rapid Wash 60 °C “from the next chapter onwards.

4 RESULTS AND ANALYSIS

As described in Table 3 under section 3.4, the determination of the tumble dry cycle time for Rapid Wash 60 °C was the 1st step of this research. The timer setting calculation method described in BS EN ISO 6330:2012 Annex P is referred to with following conditions.

i. Tumble dry load should be approximately 1 kg after drying.
ii. 100% Cotton 6 ballast washed according to Rapid Wash 60°C
iii. Exhaust temperature setting 75 °C

Table 5 shows the steps of tumble dry cycle time calculation.

Table 5: Determination of Rapid Wash 60°C tumble dry cycle

Tumble dry cycle		
Initial dry weight (conditioned mass of the load)	949.00	g
After washing	1992.95	g
Moisture retained	1043.95	g
After 20 min moisture evaporated	697.86	g
Initial dry rate	34.89	g/min
Preliminary dry cycle	29.92	min
After 30 min moisture evaporated	1020.00	g
Dry rate	34.00	g/min
Cycle time	**30.70**	min

4.1 Study 1: Proposed wash program-A trial run

Five 100% cotton single jersey fabric samples were selected at random in three different GSM categories. These samples were washed and dried according to BS EN ISO 6330:2012 and Rapid Wash 60°C washing and drying procedures. Table 6 shows the test result out comes of length shrinkage. Mean values as an average of Rapid Wash 60°C unconditioned state and BS EN ISO 6330:2012 have a difference of only 0.6%. Mean values as an average of Rapid Wash 60°C conditioned state and BS EN ISO 6330:2012 have a difference of 1.12%.During the initial stage of the research ,samples were obtained from the Hayleys Fabric PLC sample room based on the availability. Received one sample from 120 GSM, two samples from 145 GSM and two samples from 160 GSM.

Table 6: Initial washing trial length shrinkage test results

Sample	Rapid Wash 60°C (Length shrinkage)		BS EN ISO 6330 :2012 (Length shrinkage)
	Without conditioning	With conditioning	
120	-9.06%	-7.51%	-9.65%
145	-7.56%	-7.55%	-8.38%
145	-8.00%	-7.56%	-9.21%
160	-1.40%	-1.85%	-2.02%
160	-2.42%	-1.38%	-2.18%
Mean μ	-5.69%	-5.17%	-6.29%

Figure 5 shows the length shrinkage behavior of Rapid Wash 60°C fabric sample conditioned state and unconditioned state in comparison with fabric samples tested according to BS EN 6330:2012 washing and drying procedure Length shrinkage of 160 GSM fabric is nearly 2% where it shows significant decrease of length shrinkage from 145 GSM to 160 GSM. Samples that are obtained randomly have their own inherent shrinkage values with respect to the BS EN ISO 6330:2012 washing and tumble drying. Hence the significant change is accepted based on the nature of different fabric test results. Importantly Figure 5 shows that at each point Rapid Wash 60°C also provides a fairly closer trend to BS EN ISO 6330:2012 trend and test results.

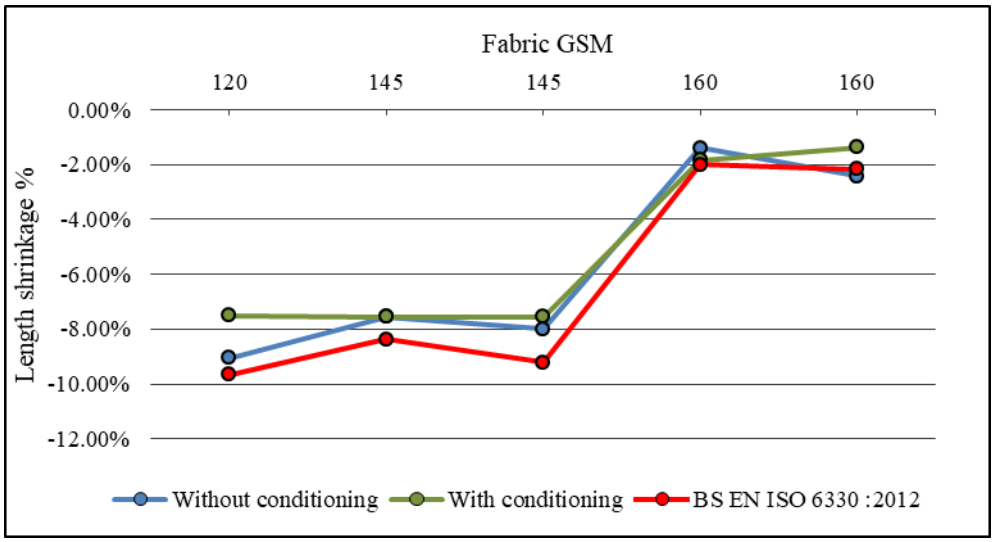

Figure 5: Length shrinkage test results: Rapid Wash 60°C vs. BS EN ISO 6330:2012

Table 7 shows the test result outcomes of width shrinkage. Mean values of Rapid Wash 60°C unconditioned state and BS EN ISO 6330:2012 has a difference of only 1.12%.Again there is a significant change in the width shrinkage values from 145

GSM to 160 GSM. Samples that are obtained randomly have their own inherent shrinkage values with respect to the BS EN ISO 6330:2012 washing and tumble drying. Hence the significant change is accepted based on the nature of different fabric test results. Importantly Figure 6 shows that at each point Rapid Wash 60°C also provides a fairly closer trend to BS EN ISO 6330:2012 trend and test results.

Table 7: Initial washing trial width shrinkage test results

Sample	Rapid Wash 60°C (Width Shrinkage)		BS EN ISO 6330 :2012
	Without Conditioning	With Conditioning	
120 GSM	-7.15%	-7.28%	-6.82%
145 GSM	-4.83%	-4.29%	-2.95%
145 GSM	-4.34%	-4.18%	-3.71%
160 GSM	-11.66%	-11.72%	-10.14%
160 GSM	-10.56%	-10.68%	-9.33%
Mean μ	-7.71%	-7.63%	-6.59%

Figure 6 shows the width shrinkage behavior of Rapid Wash 60°C fabric sample conditioned state and unconditioned state in comparison with fabric samples tested according to BS EN 6330:2012 washing and drying procedure.

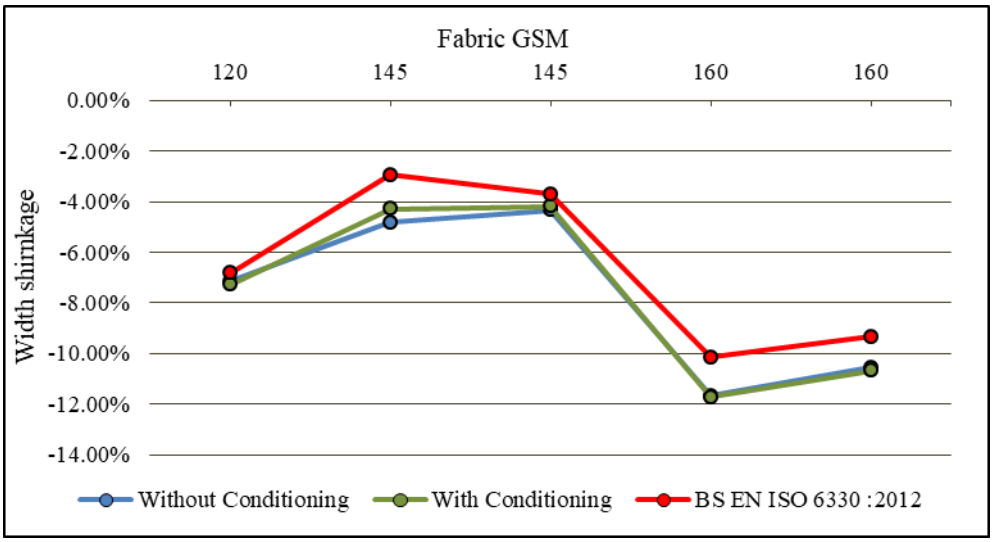

Figure 6: Width shrinkage test results: Rapid Wash 60°C vs. BS EN ISO 6330:2012

After performing the above trial run, Rapid Wash 60°C was confirmed with the given settings to perform without any concern. However figure 6 and 7 both indicate a gap between the test values of BS EN ISO 6330:2012 and Rapid Wash 60°C.

4.2 Study 2: Hydro extraction RPM

By changing the hydro extraction RPM, behavior of the Rapid Wash 60°C shrinkage test results was observed to finalize the optimum RPM value suited for Rapid Wash 60°C.Table 8 shows the shrinkage performances of 120 GSM 100% cotton single jersey fabric ,washed by changing the hydro extraction RPM from 400 to 1000.

Table 8:120 GSM fabric hydro extraction RPM and shrinkage %

RPM	Length Shrinkage %	Width Shrinkage %
400	-7.11%	-7.39%
500	-7.87%	-7.98%
600	-10.10%	-6.99%
700	-9.59%	-5.97%
800	-9.91%	-6.38%
900	-9.54%	-6.53%
1000	-9.66%	-6.25%
$\mu_{120\ GSM}$	-9.11%	-6.78%
$\sigma_{120\ GSM}$	1.15%	0.71%
$\mu_{400,500,600,700\ RPM}$	-8.67%	-7.08%
$\sigma_{400,500,600,700\ RPM}$	1.41%	0.85%
$\mu_{800.900.1000\ RPM}$	-9.70%	-6.39%
$\sigma_{800.900.1000\ RPM}$	0.19%	0.14%

Figure 7 shows shrinkage performances of 120 GSM 100% cotton single jersey fabric with different RPM settings of hydro extraction referred to table 8 above.

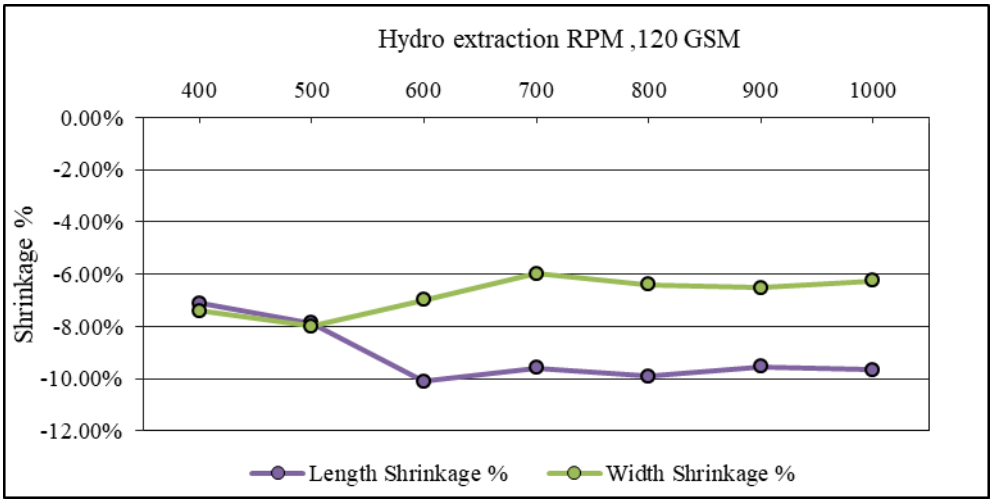

Figure 7: 120 GSM-hydro extraction RPM versus shrinkage % performances

Comparing table 8 and figure 7 it is clearly evident that after reaching 800 RPM, length and width shrinkage σ reached a very low value dropping to 0.19% from 1.41% and 0.14% from 0.85% respectively.

Table 9 shows the shrinkage performances of 145 GSM 100% cotton single jersey fabric washed by changing the hydro extraction RPM from 400 to 1000.

Table 9:145 GSM fabric hydro extraction RPM and shrinkage %

RPM	Length Shrinkage %	Width Shrinkage %
400	-4.91%	-7.15%
500	-5.33%	-6.82%
600	-5.97%	-6.28%
700	-6.25%	-5.94%
800	-7.98%	-4.18%
900	-8.20%	-4.37%
1000	-8.00%	-4.34%
$\mu_{145\ GSM}$	-6.66%	-5.58%
$\sigma_{145\ GSM}$	1.38%	1.26%
$\mu_{400,500,600,700\ RPM}$	-5.62%	-6.55%
$\sigma_{400,500,600,700\ RPM}$	0.61%	0.54%
$\mu_{800.900.1000\ RPM}$	-8.06%	-4.30%
$\sigma_{800.900.1000\ RPM}$	0.12%	0.10%

Figure 8 shows shrinkage performances of 145 GSM 100% cotton single jersey fabric with different RPM settings of hydro extraction referred to above table 9.

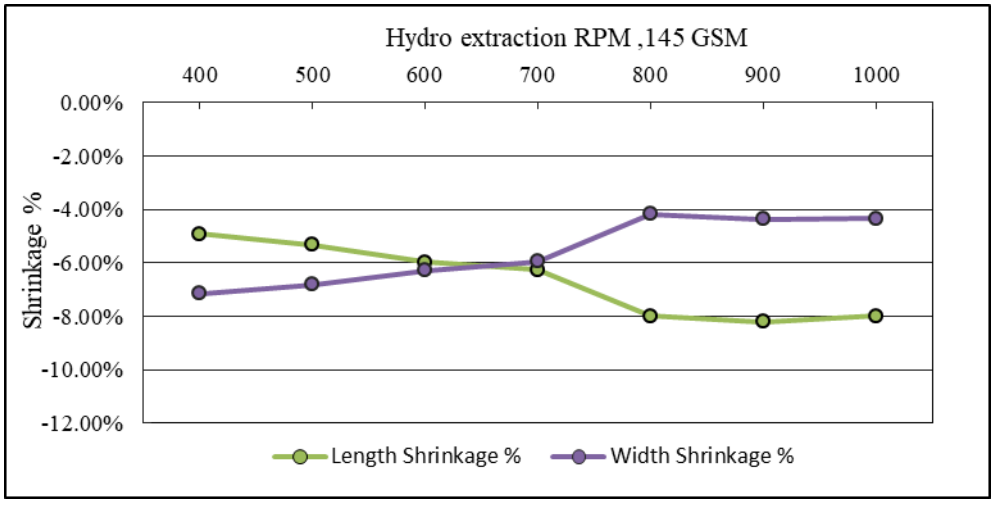

Figure 8 :145 GSM-hydro extraction RPM versus shrinkage % performances

Comparing table 9 and figure 8 it is clearly evident that after reaching 800 RPM, length and width shrinkage σ reached a very low value dropping to 0.12% from

0.61% and 0.10% from 0.54% respectively. Table 10 shows the shrinkage performances of 160 GSM 100% cotton single jersey fabric washed by changing the hydro extraction RPM from 400 to 1000.

Table 10:160 GSM fabric hydro extraction RPM and shrinkage %

RPM	Length Shrinkage %	Width Shrinkage %
400	-4.18%	-8.82%
500	-3.71%	-9.55%
600	-3.28%	-9.60%
700	-3.53%	-10.77%
800	-2.41%	-10.56%
900	-2.28%	-10.27%
1000	-2.42%	-10.56%
$\mu_{160\ GSM}$	-3.12%	-10.02%
$\sigma_{160\ GSM}$	0.75%	0.71%
$\mu_{400,500,600,700\ RPM}$	-3.68%	-9.69%
$\sigma_{400,500,600,700\ RPM}$	0.38%	0.81%
$\mu_{800.900.1000\ RPM}$	-2.37%	-10.46%
$\sigma_{800.900.1000\ RPM}$	0.08%	0.17%

Figure 9 shows shrinkage performances of 160 GSM 100% cotton single jersey fabric with different RPM settings of hydro extraction referred to table 10 above.

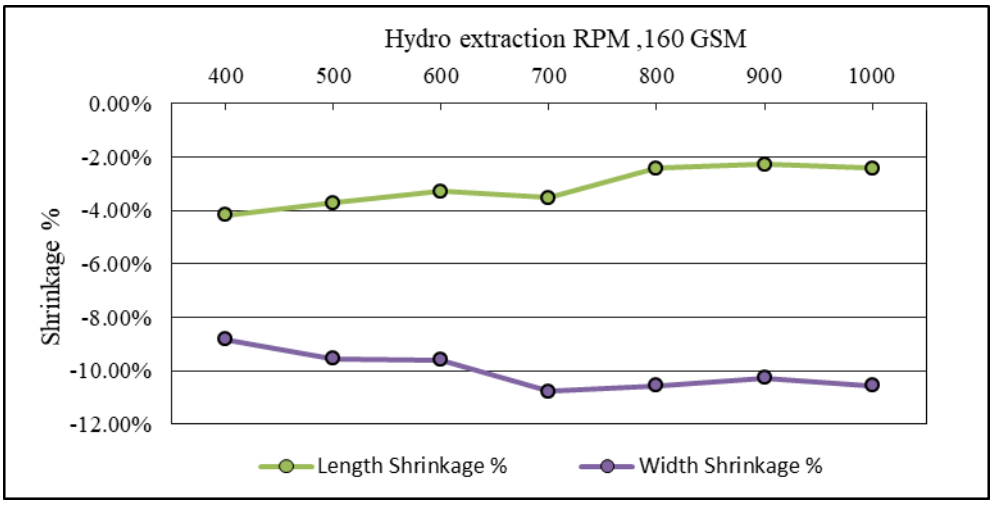

Figure 9 :160 GSM-hydro extraction RPM versus shrinkage % performances

Comparing table 10 and figure 9 it is clearly evident that after reaching 800 RPM, length and width shrinkage σ reached a very low value standard deviation dropping to 0.08% from 0.38% and 0.17% from 0.81% respectively. Thus all three cases with 120 GSM, 145 GSM and 160 GSM shows that after reaching hydro extraction RPM

800, length and width shrinkages become stable, and will not change significantly at 900 RPM and 1000 RPM. Therefore the hydro extraction RPM setting was finalized as minimum value 800 RPM. Therefore Rapid Wash 60°C washing and drying procedure was finalized as in table 11.

Table 11: Washing & drying parameter comparison

Washing & Drying Conditions	BS EN ISO 6330 :2012	Proposed Method	Remarks/Reasons
Washing Temperature	50°C	60°C	To increase the severity
Main Wash Cycle	15min	23mins	
Rinse Cycles & Duration	4 Cycles 10 mins	1 Cycle 5 mins	This will cut of water filling cycle time
Hydro Extraction (RPM)	5 mins RPM 500	2 mins RPM 800	Reduce tumble drying cycle
Total Washing Cycle	1hour 10 mins	30 mins	
Total Tumble Dry Cycle	1 hour 10 mins	30 mins	ISO 6330 Type I , 100% Cotton Ballast
Tumble dryer exhaust temperature setting	Not exceeding 80 °C for normal fabric and 60°C for delicate fabric	75°C	Should be than 80 °C for normal fabric.BS EN ISO 6330:2012
Total Time Washing & Drying	2 hours and 20 mins	1 hour	

Apart from the parameters in the above table 11, additional information required to complete the above washing and drying procedure are given in below table 12.

Table 12: Additional information for washing & drying parameter comparison

Washing & Drying Conditions	BS EN ISO 6330 :2012	Proposed Method	Remarks/Reasons
Washing Detergent	ECE Ref98, Sodium Perborate, TEAD	Persil 10g	Avoid to use top loading washing detergent
Test Specimen Size	50cm X 50cm	30 cm X 30 cm	Reduce sample size, faster tumble drying
Water added to dry load (Main Wash)	16 L	7 L	
Wash Load	2 ± 0.1kg	2 ± 0.1kg	Follows the standard
Tumble Dry Load (when samples are dried)	2 ± 0.1kg	1 ± 0.05kg	Reduce tumble drying cycle time

4.3 Study 3: Performance of the new procedure

Having met the Rapid Wash 60°C washing and drying conditions according to the above table 11 and table 12, it can be tested for performance along with standard

washing and drying procedure BS EN ISO 6330:2012.To review the test performance, it was required to repeatedly test and required more samples (longer fabric length) from one fabric material within the GSM range of 120 to 150 GSM. To fulfill this requirement Hayleys Fabric PLC management approves 150 GSM single jersey 20kg fabric roll. Using 150 GSM 100 % cotton single jersey fabric material, Rapid Wash 60°C washing and drying cycle performed for 30 samples along with the BS EN ISO 6330:2012 standard washing and drying procedure. Table 13 shows the test results data of 30 washing and drying cycles.

Table 13: Rapid Wash 60°C vs. BS EN ISO 6330:2012 test results

Sample no.	Rapid Wash 60°C without conditioning		Rapid Wash 60°C with conditioning		BS EN ISO6330 :2012	
	Length shrinkage%	Width shrinkage%	Length shrinkage%	Width shrinkage%	Length shrinkage%	Width shrinkage%
1	-9.83%	-5.67%	-9.81%	-4.47%	-8.57%	-3.71%
2	-9.83%	-6.17%	-9.81%	-5.48%	-9.26%	-4.29%
3	-10.61%	-5.22%	-10.48%	-4.30%	-9.90%	-4.30%
4	-10.17%	-6.06%	-10.09%	-5.14%	-9.62%	-4.29%
5	-9.56%	-6.61%	-9.64%	-5.42%	-9.90%	-4.57%
6	-10.92%	-4.07%	-10.56%	-4.44%	-8.57%	-5.15%
7	-9.89%	-5.17%	-10.00%	-4.10%	-10.00%	-4.10%
8	-10.83%	-4.56%	-10.92%	-4.00%	-10.00%	-4.00%
9	-11.17%	-4.61%	-10.92%	-4.10%	-10.10%	-4.10%
10	-11.11%	-5.22%	-10.86%	-4.36%	-9.05%	-4.19%
11	-10.94%	-3.83%	-10.65%	-3.18%	-10.49%	-5.62%
12	-10.44%	-3.72%	-10.47%	-2.62%	-10.55%	-4.95%
13	-11.39%	-5.67%	-11.31%	-5.08%	-10.95%	-6.75%
14	-10.94%	-5.00%	-10.76%	-4.79%	-10.95%	-4.85%
15	-11.06%	-5.50%	-10.97%	-4.75%	-10.94%	-4.85%
16	-10.28%	-5.28%	-10.75%	-5.18%	-10.17%	-4.28%
17	-11.11%	-5.50%	-11.09%	-4.59%	-11.22%	-4.76%
18	-10.06%	-4.56%	-10.53%	-4.52%	-10.93%	-3.81%
19	-8.50%	-4.83%	-9.98%	-3.69%	-10.00%	-6.19%
20	-9.72%	-4.50%	-9.82%	-3.63%	-10.28%	-5.71%
21	-9.72%	-5.11%	-9.74%	-4.02%	-10.31%	-5.71%
22	-9.44%	-6.50%	-9.36%	-5.42%	-10.00%	-6.77%
23	-9.06%	-4.78%	-8.53%	-3.74%	-9.80%	-6.21%
24	-9.78%	-5.94%	-9.58%	-4.09%	-11.12%	-5.45%
25	-9.00%	-5.83%	-8.98%	-4.87%	-10.67%	-5.33%
26	-10.67%	-5.67%	-10.46%	-4.75%	-10.00%	-6.29%
27	-9.94%	-6.28%	-9.97%	-5.37%	-11.43%	-5.15%
28	-10.89%	-5.50%	-10.80%	-4.36%	-9.44%	-6.10%
29	-11.67%	-5.39%	-11.33%	-4.53%	-11.15%	-6.10%
30	-10.78%	-5.33%	-9.81%	-4.42%	-10.47%	-7.14%

Figure 10 shows the test result line chart of 30 samples washed and dried according to Rapid Wash 60 °C conditioning without conditioning and BS EN ISO6330:2012 washing and drying procedure.

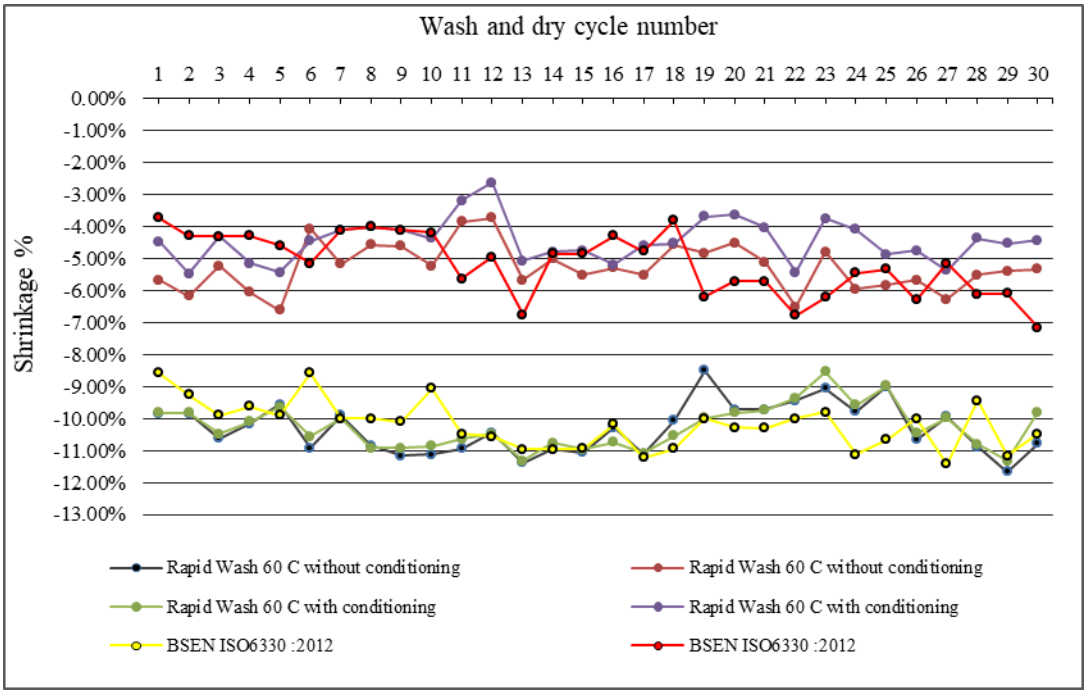

Figure 10: Rapid Wash 60°C vs. BS EN ISO 6330:2012 performance

In all three scenarios -Rapid wash 60°C conditioned, unconditioned and BS EN ISO 6330:2012 the test values do not deviate significantly. Further, this can be justified with the statistical data of mean and standard deviations of each scenario shown in table 14 below.

Table 14: Rapid Wash 60°C vs. BS EN ISO 6330:2012 statistical data summary

	Without Conditioning		With Conditioning		BS EN ISO6330 :2012 5N	
	Length Shrinkage%	Width Shrinkage%	Length Shrinkage%	Width Shrinkage%	Length Shrinkage%	Width Shrinkage%
μ	-10.31%	-5.27%	-10.27%	-4.45%	-10.19%	-5.16%
σ	0.78%	0.74%	0.68%	0.68%	0.74%	0.97%
cV%	7.54%	13.96%	6.65%	15.18%	7.29%	18.85%

It was observed that in the results in respect of three different washing conditions, the standard deviation was less than 1%.Variability of Rapid Wash 60°C was within 1% for all length and width shrinkage calculations, while the standard accelerated test method ISO 23231:2008 also indicates variability within 1 stated as follows: “Five fabrics were selected for testing and included both knits and wovens. Three replicates

of each fabric were tested in each laboratory. The average dimensional change was determined in both the length and the width directions. The standard deviation on the measurements in all cases was no greater than 1,0."(ISO 23231:2008(E), 2008). Further when comparing all 3 washing conditions for CV%, width shrinkage variability is always higher than the length shrinkage.

4.4 Study 4: Five washes trial

Fabric material used in study 3 were again tested for five washing cycles and reviewed for the performance of Rapid Wash 60°C and BS EN ISO 6330:2012.It is said that up to five wash cycles there are relatively large differences between different fabrics in dimensional stability properties however beyond five cycles changes in dimensions are small. Therefore, both methods were tested up to five wash and dry cycles to observe their behaviors. Table 15 below shows the shrinkage percentages of five washes in Rapid Wash 60°C and BS EN ISO 6330:2012.

Table 15: Five washes performance of Rapid Wash 60°C Vs BS EN ISO 6330:2012

Wash cycle		1st Wash	2nd Wash	3rd Wash	4th Wash	5th Wash
BS EN ISO 6330:2012	Length Shrinkage%	-8.99%	-2.41%	-3.28%	-3.38%	-3.48%
	Width Shrinkage%	-4.37%	-11.78%	-12.06%	-12.25%	-12.73%
Rapid Wash 60°C	Length Shrinkage%	-8.31%	-9.93%	-9.60%	-10.77%	-11.06%
	Width Shrinkage%	-6.57%	-5.62%	-6.29%	-6.79%	-7.07%
BS EN ISO 6330:2012	Area shrinkage	12.97%	13.91%	14.94%	15.22%	15.77%
Rapid Wash 60°C	Area shrinkage	14.33%	15.00%	15.28%	16.83%	17.34%

Calculated area shrinkages of Rapid Wash 60°C and BS EN ISO 6330:2012 shows that after the first wash cycle fabric can shrink further even up to the fifth wash cycle. It is a gradual increase for both procedures. Highest area shrinkage was reported in the fifth wash cycle for both test procedures. It is clearly evident that Rapid Wash 60°C reached the highest area shrinkage value among these two procedures in the fifth wash cycle showing very good response to the area shrinkage.
In the meantime BS EN ISO6330:2012 first and second wash in length and width directions shows a significant change in the test results Figure 11 shows the line chart of length shrinkage up to five washes for Rapid Wash 60°C and BS EN ISO 6330:2012.

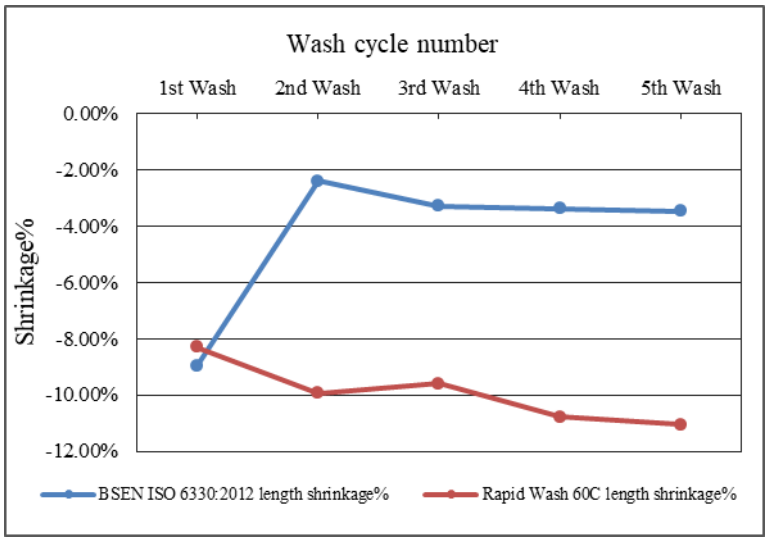

Figure 11: Five washes length shrinkage

Figure 12 below shows the width shrinkage values of five washes in Rapid Wash 60°C and BS EN ISO 6330:2012.

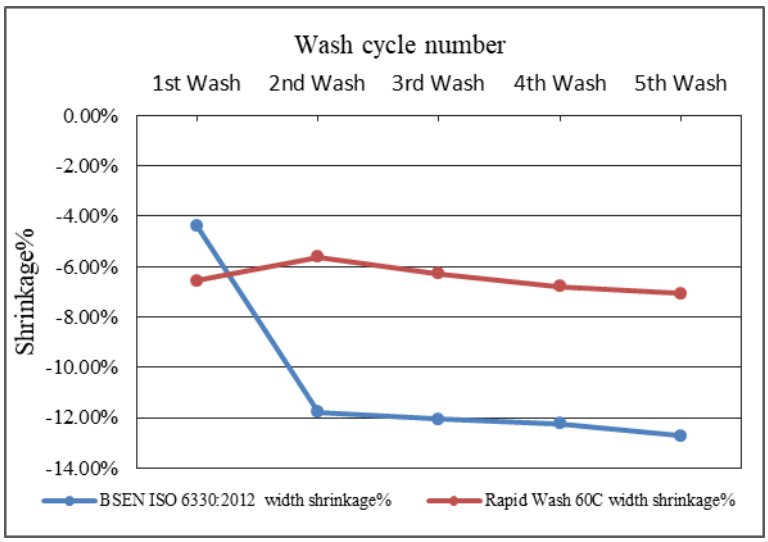

Figure 12: Five washes width shrinkage

It can be observed in figure 11, BESN ISO 6330:2012 length shrinkage decrease and getting closer to approximately- 2% from approximately- 9% in the 1st wash and figure 12,width shrinkage increased to approximately to -12% from approximately-4% in the 1stwash. Similar behavior but opposite in slope can be observed in Rapid Wash 60°C between 1st wash to 2nd wash test results.

4.5 Study 5: Relationship between two procedures

Moving forward in search of Rapid Wash 60°C performance, 100% cotton single jersey fabric samples from 120 GSM, 130GSM, 140 GSM and 150 GSM weights and three from each GSM were tested along with standard wash program BS EN ISO 6330:2012. Table 16 below presents the test results of Rapid Wash 60°C and BS EN ISO 6330:2012.

Table 16: Test results for different fabric GSM's

Sample	Without conditioning		With conditioning		BS EN ISO 6330:2012	
	Length shrinkage%	Width shrinkage%	Length shrinkage%	Width shrinkage%	Length shrinkage%	Width shrinkage%
120A	-5.06	-4.22	-4.87	-3.36	-5.80	-4.68
120B	-5.94	-5.22	-5.54	-4.19	-6.28	-5.81
120C	-5.56	-5.50	-5.27	-3.74	-5.91	-4.69
130A	-9.83	-8.11	-9.63	-7.04	-8.94	-8.10
130B	-9.28	-8.17	-9.20	-6.54	-9.61	-6.00
130C	-9.33	-5.78	-8.98	-4.64	-8.48	-5.54
140A	-5.39	-9.78	-5.31	-8.72	-5.80	-9.05
140B	-7.11	-9.72	-6.92	-9.37	-5.42	-7.25
140C	-5.78	-10.28	-5.54	-9.23	-5.72	-7.83
150A	-10.89	-5.50	-10.80	-4.36	-9.44	-6.10
150B	-11.67	-5.39	-11.33	-4.53	-11.15	-6.10
150C	-10.78	-5.33	-9.81	-4.42	-10.47	-7.14

Denote Rapid Wash 60°C length shrinkage without conditioning by *x* and length shrinkage of BS EN ISO 6330:2012 by *y*, and assume a straight-line relation. α is a constant, and β is Regression Coefficient.

$$\beta = \frac{S(xy)}{S(xx)} = 0.8186$$

$\bar{x}$ = -8.05

$\bar{y}$ = -7.75

$\alpha = y - \beta x$ = -7.75-(0.8186 x -8.05) = -1.1603

y = 0.818 x -1.1603

If the variables *x* and *y* are not related at all and that they have no relation or have nonlinear relation, Therefore assume that null hypothesis, $\beta = 0$.Table 17 below shows the ANOVA results for length shrinkages without conditioning.

Table 17 : ANOVA table for length shrinkages without conditioning

ANOVA

	df	*SS*	*MS*	*F*
Regression	1	45.33	45.33	98.56
Residual	10	4.60	0.46	
Total	11	49.92		

From F distribution tables: $F_{10,\ 5\%} = 4.96$ which means 98.56>4.96 and therefore null hypothesis, $\beta = 0$ is rejected. There was strong evidence of existence of a linear regression. Similarly a straight line was assumed for width shrinkage. Thus Rapid Wash 60°C width shrinkage without conditioning was denoted by *x* and width shrinkage of BS EN ISO 6330:2012 by *y,* and assumed a straight-line relation as below. Table 18 below shows the ANOVA results for width shrinkages without conditioning.

$y = 0.4945 x - 3.0981$

Table 18 : ANOVA table for width shrinkages without conditioning

ANOVA

	df	*SS*	*MS*	*F*
Regression	1	12.39	12.39	15.56
Residual	10	7.96	0.80	
Total	11	20.35		

From F distribution tables: $F_{10,\ 5\%} = 4.96$ which means 15.56>4.96 and therefore null hypothesis, $\beta = 0$ is rejected. There was strong evidence of existence of a linear regression.

With these findings Rapid Wash 60°C can be recommended as accelerated washing and drying procedure for urgent situations.

4.6 Test procedure

The ISO 23231:2008 test procedure consists of 13 sections. The same sections were followed to develop the Rapid Wash 60°C, new washing and drying procedure. In appendix –i washing and drying procedures were described in one section. Hence the test procedure described here contains 12 sections. Refer Appendix -i

5 CONCLUSION

Faster techniques to check the dimensional stability to washing and drying on a 100% single jersey fabric within approximately one hour creates an opportunity for fabric manufacturers to expedite their operations by reducing the testing lead time. Whenever an urgent situation arises, Rapid Wash 60°C is a test procedure developed to obtain the test result within 1 hour instead of waiting 12 hours in a traditional method BS EN ISO 6330:2012.

Predefined washing and drying conditions were tested with five different samples representing GSM values 120,145 and 160.Mean values of length shrinkage and width shrinkage from Rapid Wash 60°C unconditioned state differed only less than 1.5% from the BS EN ISO 6330:2012 washing and drying procedure. This initial study helped to finalize the proposed washing and drying procedure time durations and to confirm that defined settings are acceptable to run in a washing and drying procedure.

Hydro extraction spinning cycle is one of the key elements influencing the dimensional stability test result. It was about 24% from the total shrinkage contribution testified in the research, effect of laundering on the dimensional stability and distortion of knitted fabrics (Anand et al., 2002).Thus changing the RPM value of hydro extraction in Rapid Wash 60°C washing and drying procedure, results were reviewed from 120,145 and 160 GSM 100% cotton single jersey fabrics. It was observed that no significant changes occurred in the shrinkage after reaching the RPM 800. It was clearly evident that, after reaching 800 RPM, length and width shrinkage σ reached a very low value compared to 400,500,600,700 RPM σ value. Rapid Wash 60°C hydro extraction spinning cycle only takes about 2 minutes. If the hydro extraction duration is increased, it may effect further to the shrinkage values even at 800,900 and 1000 RPM values. Increasing the hydro extraction cycle time will also extend the total washing and drying cycle. It is contradicting the initial plan to have a shorter lead time washing and drying procedure. Results indicates when Rapid Wash 60°C is performed at 800 RPM or 1000 RPM, final shrinkage result might be very similar to each other. Therefore Rapid Wash 60°C hydro extraction

RPM is finalized as 800 RPM which would also reduce vibration, save electricity and wear and tear of the washing machine. Rapid Wash 60°C washing cycle, rinse cycle, hydro extraction cycle with 800 RPM and tumble dry cycle was finalized to perform study 3. For experiment convenience this research uses the Miele washing machine. Similar wash programs can be written in FOM CLS 71 washing machine. Research can be extended to develop a wash program also in FOM CLS 71 washing machine.

150 GSM 100% cotton single jersey fabric was tested 30 times with Rapid Wash 60°C and BS EN ISO 6330: 2012.Calculated mean values and standard deviation values of both washing and drying procedures confirms that mean values of each washing and drying procedure got less than 1 % shrinkage difference to each other and the standard deviation on the measurements in all cases was no greater than 1%.The lowest values of coefficient of variation reported from Rapid Wash 60°C is 13.96% for width shrinkage in non-conditioned state and 6.65% for length shrinkage in Rapid Wash 60°C in conditioned state against the BS EN ISO 6330:2012 washing and drying procedure. This confirms that Rapid Wash 60°C is a more consistent washing and drying procedure to implement. Further when comparing all 3 washing conditions for cV%, width shrinkage variability is always higher than its length shrinkage. As of this behavior it more accurate and less varying test result for length shrinkage than width shrinkage can be expected from Rapid Wash 60 °C.

The same material, 150 GSM 100% cotton single jersey fabric, was tested again for five wash cycles. Area shrinkage values in both washing and drying procedures shows gradual increase of shrinkage, indicating that shrinkage values increase while increasing the number of washing cycles. Rapid Wash 60°C reached the highest area shrinkage value in the fifth wash showing very good response to the shrinkage of the fabric. Rapid Wash 60°C test result in comparison with BS EN ISO 6330:2012 shows significantly different length shrinkage and width shrinkage values after the 2nd wash onwards. Hence Rapid Wash 60°C is not recommended for test result comparison after 2nd wash with BS EN ISO 6330:2012.It was noticed that there was

significant change in the shrinkage results between first wash and the second wash of BS EN ISO 6330:2012 and Rapid Wash 60°C both washing and drying procedures. Continuous washing makes the samples more relaxed and helps to reach its best free state every time. Up to 5^{th} wash area shrinkage increase of BS EN ISO 6330:2012 was 2.8% and Rapid Wash 60°C it was only 3%. It was clearly evident that during the first wash both washing techniques BS EN ISO 6330:2012 and Rapid Wash 60°C provides closer test result to each other. During the 2^{nd} wash,3^{rd} wash,4^{th} wash up 5^{th} wash length shrinkage and width shrinkage can be settled in different points for the two different washing programs depending on the way of washing stresses were applied. Area shrinkage always has an increase up to five washes. Birkett highlighted during the starfish project "up to about five cycles, there are relatively large differences between different fabrics; beyond five cycles the changes in dimensions are small and for most practical purposes can be ignored"(Birkett, 1986).Therefore we could expect a consistent pattern of width and length shrinkage values after 5^{th} wash onwards. Further research is recommended to understand these behaviors of standard washing and drying procedure.

In some international standards/buyer standards used the same dimensional stability washing and drying procedure washed specimens to evaluate the spirality of the fabric. Spirality is another important parameter to evaluate for single jersey fabric. If this parameter can be added to the Rapid Wash 60°C procedure, users can obtain fast feedback on dimensional stability as well as the spirality aspect of the fabric. Another area that should consider as an extension of this research.

Two straight lines derived for the length shrinkage and with shrinkage respectively $y = 0.8186 x -1.1603$ and $y = 0.4945 x -3.0981$.Primary axis "x "belongs to Rapid Wash 60°C values and "y" axis belong to BS EN ISO 6330:2012.The existence of these two straight-lines was confirmed with 95% confidence using ANOVA F test. Since the study 5 already confirmed the liner relationship between Rapid Wash 60°C (sample non-conditioning state) and BS EN ISO 6330:2012; for an urgent situations Rapid Wash 60°C can be followed without sample conditioning and test can be completed approximately within 1hours time.

6 REFERENCES

1. AATCC Test Method 135. (2014). In AATCC Technical Manual (2015th ed., Vol. 90, pp. 245–248). American association of textile chemists and colorists.

2. AATCC Test Method 187. (2013). In AATCC Technical Manual (2015th ed., Vol. 90, pp. 357–359). American association of textile chemists and colorists.

3. Anand, S. ., Brown, K. S. ., Higgins, L. ., Holmes, D. ., Hall, M. ., & Conrad, D. (2002). Effect of laundering on the dimensional stability and distortion of knitted fabrics. AUTEX Research Journal, 02(02), 85–100.

4. Birkett, F. H. (1986). The starfish project - an integrated approach to shrinkage control in cotton knits. Part 1: introduction and definition of the reference state" knitting international (pp. 40–42).

5. BS EN ISO 6330:2012 - Textiles. domestic washing and drying procedures for textile testing. (2012). BSI.

6. Cotton Incorporated. (2004). A guide to improved shrinkage performance of cotton fabrics (Technical bulletin No. ISP 1009) (pp. 1–16).

7. de Souza, A. A. U., Cherem, L. F. C., & Souza, S. M. A. G. U. (2010). Prediction of Dimensional Changes in Circular Knitted Cotton Fabrics. Textile Research Journal, 80(03), 236–252. https://doi.org/10.1177/0040517509105598

8. George performance standards. (2012). In Weft knitted -100% cotton & blends (QFMSF024 3.10).

9. ISO 139:2005(E)-Textiles-Standard atmospheres for conditioning and testing. (2005). Switzerland: ISO copyright office.

10. ISO 23231:2008(E) -Textiles -Determination of dimensional change of fabrics -Accelerated machine method. (2008).

11. J Spencer, D. (2001). Knitting technology (3rd ed.). Abington Hall, Abington Cambridge CB1 6AH, England: Woodhead publishing limited.

12. Malik, M. H., Malik, Z. A., Hussain, T., & Ramzan, M. B. (2013). Effect of sewing parameters and wash type on the dimensional stability of knitted garments. Autex. AUTEX Research Journal, 13(03), 90–94.

13. Mikučionienė, D., & Laureckienė, G. (2009). The influence of drying conditions on dimensional stability of cotton weft knitted fabrics. Materials Science (Medžiagotyra), 15(01), 64–68.

14. Munshi, V. G., Raje, C. R., Ukidve, A. ., & Pai, S. . (1993). Effect of laundering on mechanical properties of apparel fabrics. Colourage 2, 40(2), 34–38.

15. P1D, M. (2001). "Quick Wash" Stability & Spirality Tests for Weft Knit Fabric. M&S.

16. QuickWash Plus®. (2007). Retrieved May 12, 2016, from http://www.sdlatlas.com/product/74/QuickWash-Plus#

17. Tesco textile performance standards. (2012). In Tesco textile performance standards (Part 2).

Annexure- i

Accelerated dimensional stability test method designed for 100% cotton single jersey weft knit fabric in urgent situations

Scope

This in-house textile testing standard specifies quick wash and drying procedures. This method is recommended only for 100% cotton single jersey weft knit fabric spanning a weight range of 120 to 150 GSM. Its application is as an accelerated test for use in a production environment.

Normative Reference

These referenced documents are necessary for the application of this document. For dated references, only the edition cited applies.

- BS EN ISO 6330: 2012, Textiles Domestic washing and drying procedures for textile testing
- ISO 23231:2008(E): Textiles Determination of dimensional change of fabrics Accelerated machine method
- P1D, M. (2001). "Quick Wash" Stability & Spiraled Tests for Weft Knit Fabric. M&S.
- AATCC Test Method 135-2014 / Dimensional Changes of Fabrics after Home Laundering
- AATCC Test Method 187-2013/ Dimensional Changes of Fabrics: Accelerated

Terms and definitions

Dimensional change: Generic term for changes in length or width of a fabric specimen subjected to specified conditions

NOTE: The change is usually expressed as a percentage of the initial dimension of a specimen.

Growth: Dimensional change resulting in an increase of length or width of a specimen

Shrinkage: Dimensional change resulting in a decrease in the length or width of a specimen

Principle

This is an accelerated method for determining the wash shrinkage behavior of 100% cotton single jersey weft knit fabric. From one sample three test specimens were submitted into a short complete washing cycle.60°C washing cycle in a whirling hot water bath, and hydro extraction of the sample followed by 30 minutes tumble drying

in a precision tumble dryer. Dimensional changes are determined by comparing the distances between length and width direction benchmarks before and after a programmed test cycle.

Uses and limitations

This test method applies only to 100% cotton circular weft knit single jersey fabric spanning a weight range of 120 to 150 GSM.

Apparatus and materials

Automatic front loading washing machine Miele Professional PW 6055 Vario, Automatic Precision Tumble Dryer Type A1, the specification for Type A1 tumble dryer is given in Annex G BS EN ISO 6330:2012, Cotton Ballast (Type I) The nominal composition of 100% cotton ballast is given in Annex H BS EN ISO 6330:2012, Indelible ink marking pen referred in ISO 23231:2008, Steel Ruler marked in millimeters, Scale with 5kg capacity.

Sampling

A minimum of three specimens with different lengthwise wales and widthwise yarns in each specimen shall be taken from the sample.

Specimens

Basic preparation is the same as AATCC 135:2014 except sample size and benchmark distances changed as 30cmX30cm and 20cmX20cm respectively. Refer figure 1 below.

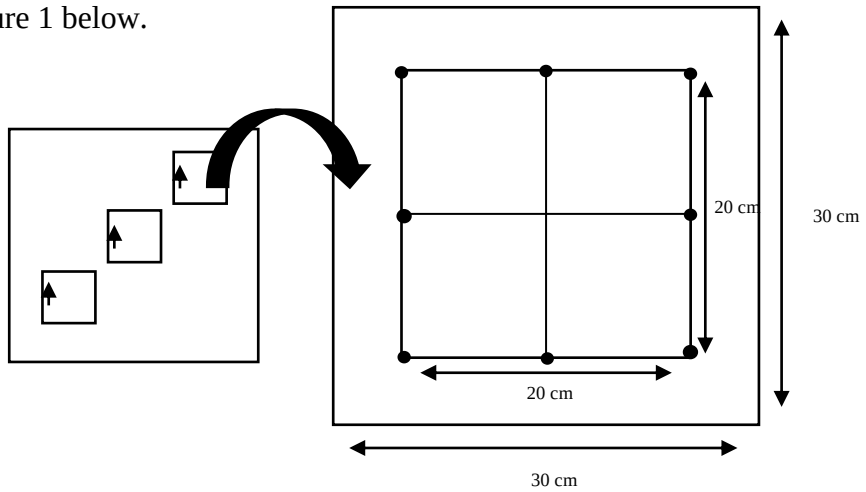

Figure 1

Reagents

Detergent having properties of heavy- duty, low- lather, powder detergent containing optical brightening agent or Persil

Conditioning and testing atmosphere

The use of standard atmospheres for textile conditioning prior to or after completion of a test not required.

Washing& Drying Procedure

Go to supervisor level of Miele Professional PW 6055 Vario automatic washing machine and arrange program settings as per the Table 1 settings for Main Wash, Rinse Cycle &Hydro Extraction. Follow other settings also included in Table 1 to arrange complete washing and drying cycle.

Table 1: Wash Program Settings

Washing Requirements	Settings
Washing Temperature	60°C
Main Wash Cycle	1392 Seconds(23 min actual time)
Rinse Cycles & Duration	1 Cycle 300 Seconds(5 min actual time)
(Hydro)Spinning Cycle & RPM	RPM 800 120 Seconds (2 min actual time)
Test Specimen Size	30 cm X 30 cm
Total Washing Cycle	30 mins (actual time)
Washing Detergent	Persil 10g
Water added to dry load (Main Wash)	Based on the dry load (Fixed 2 kg)
Tumble dryer exhaust temperature	75°C
Total Tumble Dry Cycle	30 mins
Total Time Washing & Drying	1 hour
Wash Load	2kg
Dry Load	1kg

Tumble dry cycle time setting calculation method described in BS EN ISO 6330:2012 Annex P to be referred to with following conditions.

i. Tumble dry load should be approximately 1 kg after dry.
ii. 100% Cotton 6 ballast washed according to Rapid Wash 60°C
iii. Exhaust temperature setting 75 °C

Test Report

Type of machine and washing procedure used, Drying procedure and type of the machine, Type of Detergent used, Type of Ballast used. Calculate dimensional change as below for both length and width directions.

Average DC% =100(B-A)/A; where

DC : Average dimensional change

A : Average Original dimension (distance between the benchmarks before wash)

B : Average dimension after washing (distance between the benchmarks after wash)

Both the average original and average final dimensions are the averages of the measurements in each direction made on all test specimens. Then calculate the length and width dimensional change averages separately to the nearest 0.1%.