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# A New Method for Predicting a Relationship Between the Mechanical Properties and Denim Garment Shrinkage Using the Principal Component Analysis Method

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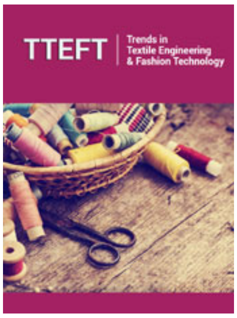


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## Abstract

**Purpose:** The purpose of this work is to study the relationship between the fabric mechanical properties such as Tear strength (T_S), Breaking strength (B_S) and Cloth's Dimensional Stability (Sh), particularly, after industrial launderings (stone wash, enzyme wash, mixed wash and rinse). Hence, we attempt to select the most interrelationships using the Principal Component Analysis (PCA) technique. In this study, the treatments of finishing garments during washing are the important parameters influencing cloth's dimensional and the fabric mechanical properties. To improve the obtained results, the selected significant inputs are also analyzed within their influence on shrinkage. The polynomial regression model relating the Tear strength and the shrinkage denim fabric proves the effectiveness of the PCA method and the obtained findings.

**Design/methodology/approach:** To investigate the matter, the type of washing and their contributions on shrinkage, four types of fabrics manufactured into pants were used. These fabrics differ not only by their basis weights (medium and heavy weight fabrics) but, also by their compositions (within and without elastane), and their thread count (warp and weft yarn count, twist and density. To evaluate significantly results, a factorial design analysis based on an experimental design was established. The choice of these treatments, as well as their design mode, led us to make a complete factorial experimental design.

**Findings:** According to the results, the prediction of shrinkage behaviour as function of the process washing input parameters seems significant and useful in our experimental design of interest. As a consequence, it was concluded also that after these input parameters, we can find the relationship between the shrinkage and the mechanical properties Tear strength (T_S warp) and Tear strength (T_S weft). Thanks to the PCA, it is very easy to reduce the number of the influent output parameters, and knowing these significant parameters, the prediction of mechanical properties knowing the shrinkage denim garment, during the process of washing seems successful and can undoubtedly help industrial to minimize the poor workmanship of the finishing quality.

**Practical implications:** This study is very interesting for finishing denim garment. The shrinkage is very important for correcting measures in sewing, considering that a high shrinkage may causes the cancellation of the fit from the client. This type of defect cannot be repaired in the major part of the cases and causes a big lost for the company, moreover the mechanical properties. For this reason, analysing the value of shrinkage before starting the production cycle is of great importance to apply the right balance to the pattern. The model of predicting the mechanical properties behaviours as function of the shrinkage denim garment leads manufacturers to eliminate the test of mechanical properties that remain as destructive tests. Moreover, according to results obtained, it may be concluded that prediction still accurate through the shrinkage test which is an inevitable test. Even thought, these results can bring a huge gain for the garment wash industries.

**Originality/value:** This work presents the first study predicting a relationship between the mechanical properties and denim garment shrinkage, applying the PCA technique to minimize the all-output parameters which are not significant or correlated with each other. Besides, it deals with the relationship developed between the fabric mechanical properties such as Tear strength (T_S), Breaking strength (B_S) and Cloth's Dimensional Stability (Sh), particularly, after industrial launderings (stone wash, enzyme wash, mixed wash and rinse). Moreover, it is notable to mention that the originality of this study is to let the garment wash industries to save in production time of orders and also in quality.

**Keywords:** Denim fabric; Principal component analysis; Shrinkage; Mechanical properties; Laundering

## Introduction

The treatment of the prepared garment (ready-to-wear), particularly the laundering and the special treatments on denim blue jeans garments are much spilled in the world. The treatments of finishing garments during washing are the important parameters influencing cloth's dimensional and the fabric mechanical properties. The washing process stone wash, enzyme wash, mixed wash and rinse in finishing garments is advisable to have more and more increased whiteness. Nevertheless, all these treatments that cause a more worn appearance and aged look for garment reduce greatly the mechanical properties and increase a lot the cloth's shrinkage. For this reason, the survey of the natural relationship between the mechanical properties and the shrinkage is asked.

Thus, we were interested in studying the effect of matter and types of launderings (stone wash, enzyme wash, mixed wash and rinse) applied during the manufacturing process of garment washing on mechanical properties and cloth's dimensional stability.

Therefore, studies dealing with this subject are not numerous and most of them treat the influence of the home laundering on some mechanical properties (dimensional stability, wrinkling) [1,2], surface roughness [3], pilling and edge abrasion [4]. Firstly, we started with a determination of the effect of matter, types of launderings (stone wash, enzyme wash, mixed wash and rinse), special treatments (brushing, sanding, resin treatment, bleach-treatment, permanganate-spray and softening) and their succession, carried out under industrial conditions, on the fabric mechanical properties by measuring the tear strength (T_S) and the breaking strength (B_S) values for different lines of finishing.

Indeed, the deterioration of the matter during the finishing processes usually leads to an uncontrolled shrinkage, which prevents the finishers from reaching the cloth shade and effect required by the customers. Moreover, reproduction to get the same finishing effects is very difficult with the currently methods followed by the different manufacturers [5-7]. There are many reasons that can justify the interest in denim fabrics. In fact, it is highly used as a basic fabric to make garments and some denim garments have high value and need to resist against the efforts and movements carried out by the person. Moreover, it should have at least two important characteristics: a longer lifespan than other types of clothing and comfort.

Regarding the large space of experimentation used, the number of tested denim fabrics and the different types of laundering of washing denim fabrics, it can be concluded that this work could be useful for industrialists. As users, it is very important that garments made in denim fabrics have no shrinkage and it preserves its mechanical properties after use. Hence, the aim of our work is to find the input combination (s) which guarantees that. The principal component analysis can help to carry out the best one which can also find relationships between both inputs and outputs and this is the originality of our contributions.

The objective of this study is to try to minimize the output parameters and to look for correlations between the mechanical properties and the shrinkage of the garment in order to minimize the tests carried out which are expensive for the manufacturer because they are destructive tests. That is why industrialist just need to control one significant input/output parameter which can predict the behaviours of the other ones. Therefore, this work deals with the evaluation and prediction of the mechanical properties and cloth shrinkage after selecting the significant and influential input parameters (types of matter and process of laundering). Hence, we attempt to select the most interrelationships thanks to the Principal Component Analysis (PCA) [8-10].

Principal component analysis today is one of the most popular multivariate statistical techniques. It is a statistical procedure that summarizes the information content in a large data table (inputs or outputs) to be more easily controlled and analysed. Besides, it can help to identify the correlations existing between either the data points or the outputs.

The output of PCA are these principal components, the number of which is less than or equal to the number of original parameters. Less, in case when we want to reduce the number of the studied inputs or outputs in our dataset. These results are too beneficial for manufacturers who always want to optimize their production costs.

## Materials and Methods

Four types of fabrics manufactured into pants were used. These fabrics differ not only by their basis weights (medium and heavy weight fabrics) but, also by their compositions (within and without elastane), and their thread count (warp and weft yarn count, twist and density) (Table 1).

**Table 1:** Fabric Specifications.

| Fabric Code | Composition | | Mass (g/m²) | Yarn count (tex) | | Twists (tr/m) | | Yarn Density | |
|---|---|---|---|---|---|---|---|---|---|
| | Warp Yarn | Weft Yarn | | Warp Yarn | Weft Yarn | Warp Yarn | Weft Yarn | Warp Density (picks/cm) | Weft Density (ends/cm) |
| T1 | 100% cotton | 96% cotton / 4% elastane | 367 | 59 | 50 | 600 | 635 | 30 | 23 |
| T2 | 100% cotton | 96% cotton / 4% elastane | 465 | 82 | 50 | 500 | 635 | 30 | 22 |
| T3 | 100% cotton | 100% cotton | 368 | 82 | 60 | 500 | 635 | 30 | 22 |
| T4 | 100% cotton | 100% cotton | 450 | 60 | 50 | 500 | 589 | 28 | 19 |

The manufactured pants were finished by different processes of washing. All wet processing is done in an industrial rotating drum machine loaded with 80kg of cloths (about 140 trousers). The recipes and treatment conditions are given in Table 2. It in notable too that at the end of wet processing the garments are extracted then dried in a tumbler at 95 °C during 45 min.

**Table 2:** Finishing processing conditions.

| Treatments | Conditions |
|---|---|
| Rinse | 1-Desizing at 50 °C during 30min with 2% amylase, 1% anti-back-staining agent and LR = 1/5<br>2-Rinsing with cold water during 2min and LR =1/10 |
| Enzymatic wash | 1-Desizing at 50 °C during 30min with 2% amylase and 1% anti-back-staining agent, LR = 1/5<br>2- Rinsing with cold water during 2min and LR =1/10<br>3- Enzymatic washing at 50 °C during 45min with 1.5% of cellulase enzyme and 1% anti-back-staining agent, LR = 1/5<br>4- Rinsing with cold water during 2min and LR =1/10 (80kg for a load of 140 trousers) |
| Stone wash | 1-Desizing at 50 °C during 30min with 2% amylase, 1% anti-back-staining agent and LR = 1/5<br>2- Rinsing with cold water during 2min and LR =1/10<br>3-stone washing at 50 °C during 45min with 50% of pumice stones, LR = 1/5<br>4- Rinsing with cold water during 2min and LR =1/10<br>5- remove the stones<br>6- Rinsing with cold water during 2min and LR =1/10<br>Temperature = 50 °C<br>Time of washing = 45 min<br>Stone: new stones and worn-out stones (80kg for a load of 140 trousers) |
| Mixed wash | 1-Desizing at 50 °C during 30min with 2% amylase and 1% anti-back-staining agent, LR = 1/5<br>2- Rinsing with cold water during 2min and LR =1/10<br>3- Mixed washing at 50 °C during 45min with 25% of pumice stones, 1.5% of cellulase enzyme and 1% anti-back-staining agent, LR = 1/5<br>4- Rinsing with cold water during 2min and LR =1/10<br>5- remove the stones<br>6- Rinsing with cold water during 2min and LR =1/10<br>(80kg for a load of 140 trousers) |

The measures of Tear strength $T_s$ and Breaking strength $B_s$ of apparel have been achieved after every treatment [7].

The fabric shrinkage was measured in two parts of the treated pants: hip zone (weft direction) and leg zone (Warp direction) according to ISO Standards 3759 and 5077 for the preparation, marking and measuring of dimensional change in textile fabrics and garments after a specified treatment such as washing, soaking in water and steaming (NFG07- 123).

The shrinkage is calculated using equation 1.

$$Sh\%=\frac{(L_o-L)}{L_o}\times 100 \quad (1)$$

Where:

*Sh*: The shrinkage of the tested fabric after treatment

$L_0$: The initial length of the tested fabric

*L*: The length of the tested fabric after treatment

To evaluate significantly results, a factorial design analysis based on an experimental design presented in Table 3, was established. The choice of these treatments (as factors), as well as their design mode, led us to make a complete factorial experimental design (4x4) with five washing processes containing 16 lines or types of experiments [11]. This plan is repeated 3 times which means that 48 experiments were conducted under industrial conditions to realise our factorial plan.

**Table 3:** Experimental design.

| Factors/ Levels | Type of fabric | Washing Types |
|---|---|---|
| 1 | T1 | Rinse |
| 2 | T2 | Enzymatic |
| 3 | T3 | Stone |
| 4 | T4 | Mixed (stone and enzyme) |

## Result and Discussion

### Experimental

The study of mechanical properties involves destructive testing of the matter which leads to financial losses for manufacturers of textile clothing. These results lead and encourage us to predict the mechanical properties of the fabric after washing without going through destructive tests. Indeed, the aim of the present study is to look for a scientific link that gives us ideas on mechanical properties through other non-destructive testing like shrinkage.

The experimental Tear strength $T_s$ (), Breaking strength $B_s$ and shrinkage values were presented in Table 4. Each test is repeated 3 times with a coefficient of variation value (CV%) less than or equal to 1%.

**Table 4:** Experimental results.

| Type of Fabric | Washing Types | $T_s$ warp (daN) | $T_s$ weft (daN) | $B_s$ warp (daN) | $B_s$ weft (daN) | $Sh_{warp}$ (%) | $Sh_{weft}$ (%) |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 6.314 | 4.416 | 69 | 47 | 4.41 | 2 |
| 1 | 2 | 5.32 | 4.16 | 73 | 43 | 4.81 | 2.23 |
| 1 | 3 | 6.208 | 3.904 | 66 | 48 | 4.66 | 2.14 |
| 1 | 4 | 4.16 | 3.008 | 50 | 41 | 5.85 | 2.51 |
| 2 | 1 | 5.76 | 4.12 | 68 | 66 | 6.55 | 2.04 |
| 2 | 2 | 4.032 | 3.648 | 61 | 57 | 7.23 | 2.3 |

 

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2 | 3 | 4.224 | 4.288 | 64 | 60 | 7 | 2.15 |
| 2 | 4 | 2.816 | 2.88 | 49 | 54 | 9.62 | 2.57 |
| 3 | 1 | 4.736 | 3.776 | 75 | 59.5 | 4.34 | 1.88 |
| 3 | 2 | 3.712 | 3.968 | 61 | 55 | 4.72 | 2.09 |
| 3 | 3 | 3.968 | 4.16 | 60 | 58 | 4.59 | 1.99 |
| 3 | 4 | 2.24 | 2.886 | 45 | 52 | 5.76 | 2.31 |
| 4 | 1 | 6.592 | 4.352 | 90 | 53 | 6.43 | 2.02 |
| 4 | 2 | 5.312 | 2.88 | 85 | 38 | 7.11 | 2.26 |
| 4 | 3 | 5.376 | 3.52 | 78 | 54 | 6.85 | 1.98 |
| 4 | 4 | 3.648 | 2.368 | 74 | 39 | 9.51 | 2.52 |

## Principal component analysis (PCA)

The PCA is a statistical method of description and reduction of studied parameters. The main idea of principal component analysis (PCA) is to reduce the dimensionality of a data set consisting of many variables correlated with each other, either heavily or lightly, while retaining the variation present in the dataset, up to the maximum extent. Its goal is to find correlations between the data (inputs and outputs) and to represent the influence of the inputs/outputs. PCA remains a powerful technique for extracting structure from possibly high-dimensional input data sets. It is readily performed by solving an eigen value problem. It consists in the projection of the input data on two axes known as principal components. A small number of principal components are often sufficient to summarize most of the structure in the input data. Besides, the PCA method amplifies subjectively the weight of certain parameters while it dampens others that are less relevant to output values [11-15].

The correlated parameters are grouped together inside the circle with radius 1 (Figure 1). When the parameters are near 1 and -1, they are considered as important. Whereas they are considered as non- significant when they are close to the center of this circle. The overall variables which are set in one of the rounds or circles are variables known as correlated positively because they evolve/ move in the same way. Thus, a variation (the increase or decrease) by one parameter will cause the variation (the increase or decrease) in the same way of the others. However, according to PCA method foundations, the groups of variables encircled together, which are opposed by one of the axes (*Y*-axis or *X*-axis) of the trigonometrically circle are correlated negatively.

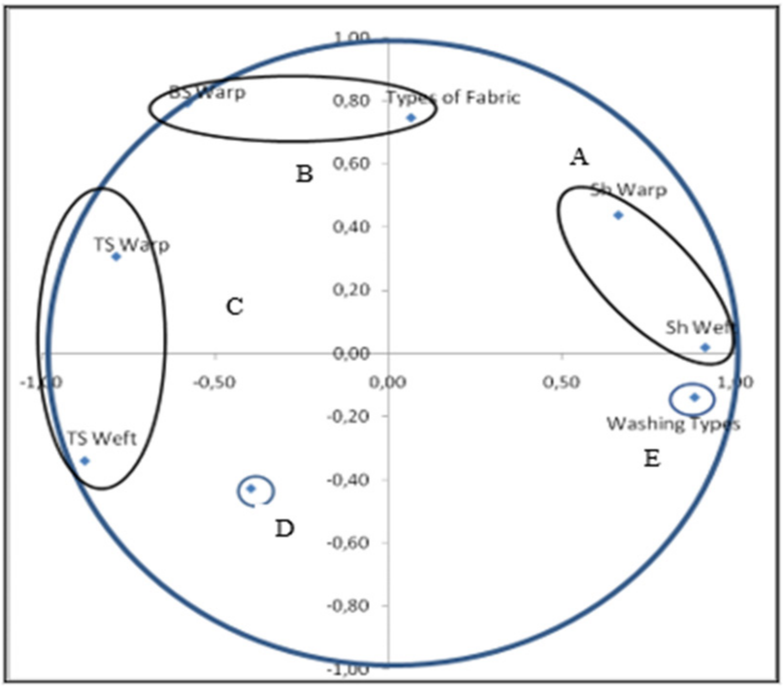


**Figure 1:** Example of the applied PCA technique.

Furthermore, the groups of variables which have symmetrically opposite direction relative to the horizontal axis are positively correlated (Groups A and E). It means that the increase of one parameter of the group entails, as a consequence, the increase in the other group. Hence, the variation of one parameter will cause the variation of the others in the same way. Then, the groups of variables which are opposed by one of the axes of the trigonometrically circle are correlated negatively (Groups A and C). Indeed, the increase in the value of any variable causes the reduction on the other.

 

In order to represent the fabric and types of washing effect on the mechanical properties and shrinkage behaviours, the PCA has been applied using the MATLAB 7.1 software. This statistical technique offers a simple and reliable way to compare samples and to find the correlations between the original variables. In addition, the PCA allows the reduction of the number of the input and output parameters.

Table 5 highlights the percentage of each parameter in each principal component. It can be seen that six overall principal components were obtained through PCA. In this paper, the parameter for which the percentage exceeded 50 percent was considered as the important element to the principal component [16-19].

**Table 5:** Principal component coefficients relative to the different variables.

| Inputs/Outputs | Factor 1 | Factor 2 | Factor 3 | Factor 4 | Factor 5 | Factor 6 | Factor 7 | Factor 8 |
|---|---|---|---|---|---|---|---|---|
| Type of Fabric | 1.00 | 0 | -0.12 | -0.32 | 0.47 | 0.01 | 0.34 | -0.15 |
| Washing Types | 0 | 1.00 | -0.69 | -0.69 | -0.61 | -0.32 | 0.45 | 0.72 |
| TS warp (daN) | -0.12 | -0.69 | 1.00 | 0.59 | 0.74 | -0.06 | -0.36 | -0.57 |
| TS weft (daN) | -0.32 | -0.69 | 0.59 | 1.00 | 0.26 | 0.51 | -0.63 | -0.76 |
| BS warp (daN) | 0.47 | -0.61 | 0.74 | 0.26 | 1.00 | -0.16 | -0.02 | -0.47 |
| BS weft (daN) | 0.01 | -0.32 | -0.06 | 0.51 | -0.16 | 1.00 | -0.13 | -0.52 |
| Sh warp (%) | 0.34 | 0.45 | -0.36 | -0.63 | -0.02 | -0.13 | 1.00 | 0.67 |
| Sh weft (%) | -0.15 | 0.72 | -0.57 | -0.76 | -0.47 | -0.52 | 0.67 | 1.00 |

**Table 6:** The variance attributed to each obtained principal factor.

| Inputs/Outputs | Factor 1 | Factor 2 | Factor 3 | Factor 4 | Factor 5 | Factor 6 | Factor 7 | Factor 8 |
|---|---|---|---|---|---|---|---|---|
| Variance | 3.93 | 1.79 | 1.22 | 0.62 | 0.25 | 0.13 | 0.04 | 0.02 |
| Pourcentage | 49.11 | 22.37 | 15.28 | 7.73 | 3.11 | 1.62 | 0.5 | 0.29 |
| Cumulative % | 49.11 | 71.49 | 86.76 | 94.49 | 97.59 | 99.21 | 99.71 | 100 |

Table 6 shows that, the PCA extracted three factors with eigenvalues >1, which accounted for 86.76% of the variance in total.

Based on many published works [17-21] the principal factors having a cumulative percentage of variance ⩾70 % can be considered the most significant ones in the PCA. In this case, the first two components explain 71.49% of the total variance. Such a large cumulated percentage value indicates that the interpretation of the results can be restricted to these two axes.

Figure 2 shows the attribute projections on the first correlation circle. The first principal component accounting for 49.11% of the variance had a high loading for the frictional parameters, the types of fabric and the washing types, which have a coefficient ⩾70%.

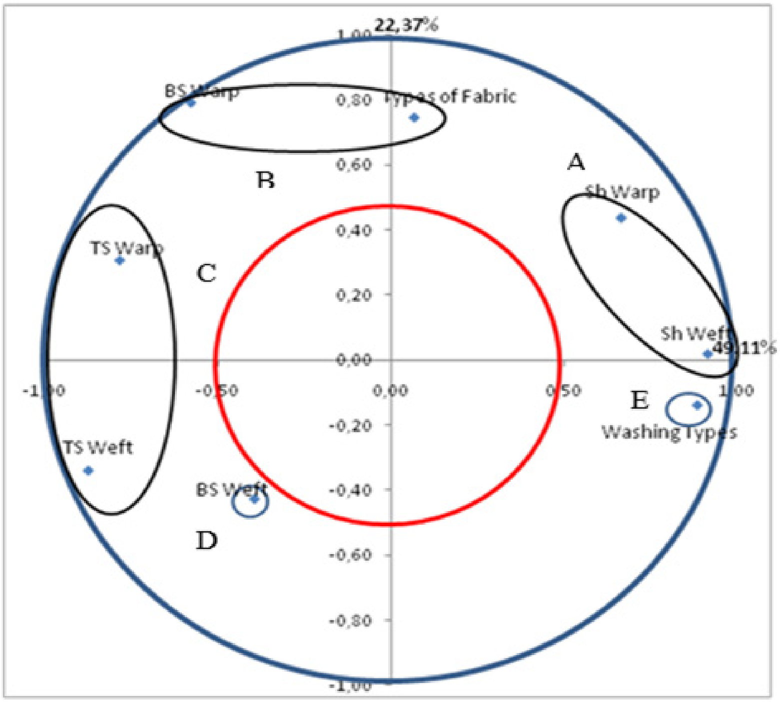


**Figure 2:** Processing of the results with principal component analysis (PCA) on the first and the second axis.

The group A is composed by two outputs $Sh_{warp}$ and $Sh_{weft}$ which are correlated positively. The increase or decrease of the one output generated the increase or the decrease of the other output (s). This finding seems important and can explain widely the variation of the shrinkage of garment after washing. Predicting shrinkage is very important before the wash cycle either in warp direction or weft one. Hence, it can help manufacturers to produce a good quality and tailor-made clothing. The existence of a relationship between warp shrinkage and weft shrinkage can minimize the number of tests carried out by the manufacturer to predict shrinkage. Notwithstanding, it can be a source of saving in time and money.

Furthermore, group A and E are positively correlated, the shrinkage properties ($Sh_{warp}$, $Sh_{weft}$)and the studied washing types (rinse, enzyme wash, stone wash and mixed wash).

When designers choose their style modes (fabric and pattern). In fact, they need to think about the most suitable way to finish the garment. While choosing a succession of finishing treatments to attempt the cloth shades and cloth effects with respect to the requests made by customers, the ratio of shrinkage continuously and slightly increase. Otherwise, the increase in the ratio of shrinkage is due to the high level of mechanical abrasion progressively generated on the fabrics by the type of washing methods: the chemical action of the enzyme and the abrasion of the stones. These results are in a good agreement with our previous work [22], dealing with the evaluation of the washing process effect applied to different types of fabrics.

Similarly, group B is composed of two parameters, breaking strength (warp) and the types of fabrics which are positively correlated.

Wet laundering is done in the presence of enzymes which allow removing the glue attached to the warp fibres. The amount of glue removed by this agent represents the decrease in the basis of weight. Thus, the washing processes are influential but with different degrees of importance on the mechanical properties such as breaking strength. By classifying the influence significance of parameters, it can be concluded that this influence comes first from the desizing agent (alpha-amylases) used in the preparation. Secondly, it comes from the products used during washing either the enzyme in the enzymatic process (cellulase) or the pumice stones in the stone process, or the double effect in the mixed process. This finding is in a good agreement with our previous work [5].

Nevertheless, the group C is composed of two parameters The Tear strength ($T_s$ warp) and Tear strength ($T_s$ weft) which are positively correlated. This result is very beneficial for manufacturers to know that the tear strength is positively correlated with both the investigated tear strengths in the two directions. Otherwise, if the warp threads are affected and their strength decreases, the weft threads behave in the same way. Therefore, just look for the equation that links the two parameters. This result saves us time and material because the fact of making tear tests, we will lose material which is expensive since the tests are destructive.

Similarly, the groups C and D are positively correlated. This link between the two properties allows manufacturers to decrease the tests to be carried out to predict the limit of mechanical properties of the garment after finishing.

In addition, the groups A and C are correlated negatively; the increase or decrease of the input generated the increase or the decrease of the shrinkage and Tear strength of denim garment. This finding seems important and can help understanding the variation of the effect of types of fabric. The process of laundering can affect in the same direction the shrinkage and the mechanical properties. Moreover, this result confirms that the types of fabric and the washing process have a common significant parameter causing shrinkage and destroy matter.

The shrinkage is very important for correcting measures in sewing, considering that a high shrinkage may causes the cancellation of the fit from the client. This type of defect cannot be repaired in the major part of the cases and causes a big lost for the company, moreover the mechanical properties. For this reason, analysing the value of shrinkage before starting the production cycle is of great importance to apply the right balance to the pattern.

Since the fabrics studied are twill with chain effect and the washing treatment is carried out wet in the presence either of an amylase in the desizing part (rinse washing) or of an enzyme (cellulase) in the three other types of washing, cellulase helps remove imperfections and / or surface fluff typical of cellulosic fabrics and it works deeper to achieve loss of strength. This is because the enzyme degrades cellulose by specific catalytic action on the 1,4 β-glucosic bonds of the cellulose molecule. The hydrolysis of this kind of bonds breaks the molecule into several pieces, which can themselves be split later (dissociation of the long molecule from the cellulosic chain). Hence, a greater drop in mechanical strength is accompanied by a large shrinkage. So, the type of laundering (rinse, enzyme wash, stone wash and mixed wash) has a significant influence on the cloth shrinkage and mechanical properties.

## Prediction of the mechanical parameters behaviours as function of the shrinkage denim garment

In this part of study, we carry out models predicting the mechanical properties behaviours as function of the shrinkage denim garment, the polynomial regression technique is applied to improve the relationships found and the model presenting the Tear strength in warp direction ($T_s$ warp) as function of shrinkage denim garment in warp direction ($Sh_{warp}$). This regression coefficient ($R^2$=0.7194) value indicates how well the model fits experimental database. In fact, the highest $R^2$ (very close to 1) gives the best model fits tested data [23-26].

We found that the prediction of shrinkage behaviour as function of the process washing input parameters seems significant and useful in our experimental design of interest. As a consequence, it was concluded also that after these input parameters, we can find the relationship between the shrinkage and the mechanical properties Tear strength ($T_s$ warp) and Tear strength $T_s$ weft [27]. We can conclude, for a forecast on the deterioration of mechanical properties we recur the dimensional stability test, the fact calculates the removal of an article directly gives us an idea on the mechanical behaviour of the garment (Figure 3).

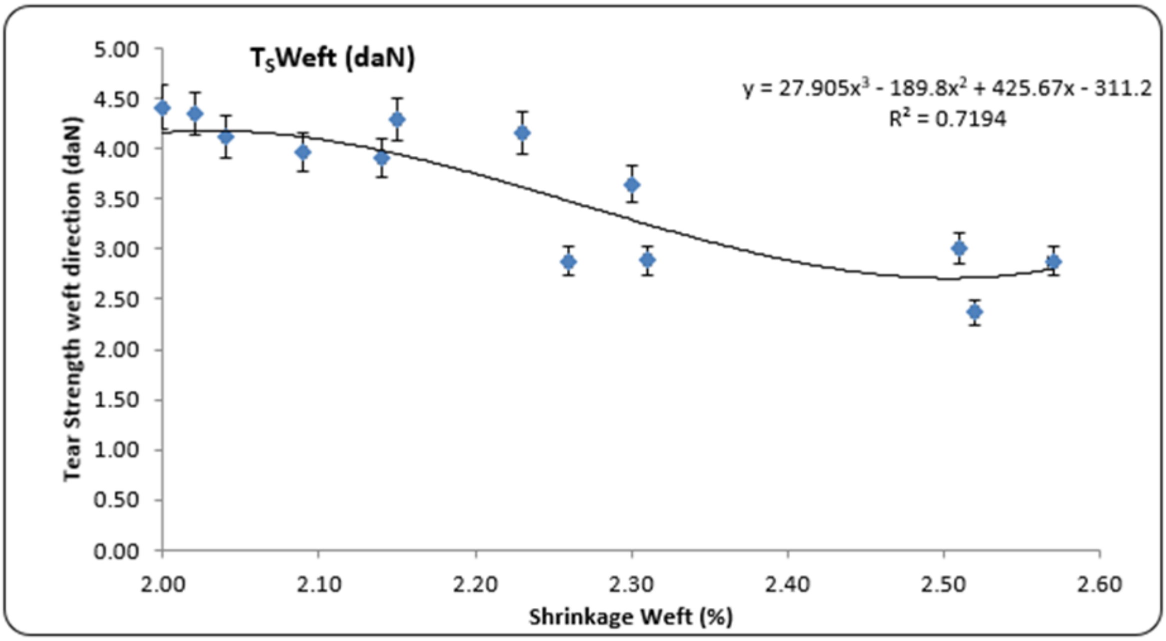


**Figure 3:** $TS_{weft}$ evolution as a function of $Sh_{weft}$ denim garment.

$$Y = 27.905X^3 - 189.8X^2 + 311.2 \quad (2)$$

Where:

Y: Tear Strength in weft direction, $TS_{weft}$

X: Shrinkage property in the weft direction, $Sh_{weft}$

## Practical validation

The validation of the model regression was carried out under industrial conditions where the different types of laundering are applied in a washing machine of 100kg of garments (details of the machine may be added). Three types of pocket jean pants are tested in three different production outputs. The difference between the three samples remains in the nature of the fabrics and the type of the process of washing. Information regarding the type of industrial orders and customers is not mentioned in this study and it is up to the company's privacy (Figure 4).


**Figure 4:** Three samples of pants investigated practically in a manufactory for model validation.

The shrinkage measurement is done according to the (ISO5077). The tear strength is calculated using the regression equation found in the present study. The results of the tests carried out are presented in Table 7.

**Table 7:** Fabrics relative to three tested pants' specifications.

| Fabric Bode | Composition | | Basis Weight (g/m$^2$) | Industrial Results | | Regression Model of $TS_{weft}$ (daN) |
|---|---|---|---|---|---|---|
| | Warp Yarns | Weft Yarns | | $Sh_{weft}$ (%) | Tear strength $Sh_{weft}$ (daN) | |
| Reference 1 | 100% Cotton | 96% cotton / 4% elastane | 360 | 2.3 | 3.3 | 3.32 |
| Reference 2 | 100% Cotton | 100% Cotton | 420 | 2.5 | 2.75 | 2.74 |
| Reference 3 | 100% Cotton | 96% cotton / 4% elastane | 340 | 2 | 4.25 | 4.18 |

To investigate the effectiveness of applied method, theoretical and experimental values are compared. The difference between these results can improve the efficiency of developed regressive model. Equation 3 presents the error expression ($E_{rr}$ (%) as function of the experimental and theoretical values.

$$E_{rr}(\%)\frac{(y-\tilde{y})}{y}\times 100 \quad (3)$$

Table 8 summarizes the theoretical results estimated by the regression equation (predicted TS weft direction) as well as those relative to experimental ones for each reference and the measured TS weft direction after production. In addition, it shows the error range values for all studied fabrics of pants. These results show that the difference between the experimental and theoretical values of the measured Tear strength are accurate. In fact, they are ranged from -0.58% to 1.65% which reflect that the established model can be useful for industrialists giving them a practical confirmation.

**Table 8:** Results of measurements.

| Fabric code | Predicted TS (weft) daN $\tilde{y}$ | Measured TS (weft) daN $y$ | $E_{rr}$ (%) |
|---|---|---|---|
| Reference 1 | 3.32 | 3.3 | -0.58 |
| Reference 2 | 2.74 | 2.75 | 0.34 |
| Reference 3 | 4.18 | 4.25 | 1.65 |

Theoretically, the final regression equation (see Equation 4) of a manufactured garment can be as follow:

$$y=\tilde{y}\pm 1.65\% \quad (4)$$

Where:

y: Coded measured Tear strength $TS_{weft}$

$\tilde{y}$: Predicted Tear strength in its coded form.

Hence, Equation 4 can be presented in its uncoded form as shown in Equation 5:

$$\text{Tear Strength (daN)}=27.9Sh^3-189.8Sh^2+425{,}67Sh-311.2\pm 1.65\% \quad (5)$$

## Conclusion

This study provided contribution in industrial products engineering, particularly those relative to denim fabrics due to their high popularity and consumptions in the markets. Indeed, the use of the PCA allows the industrialists to reduce the number of variables and make the information efficient, realistic and less redundant due to some positive or negative interrelationships.

The output parameters (mechanical properties and shrinkage) of a denim garment according to the industrial conditions of washing are minimized and reduced objectively, thanks to PCA technique. Moreover, based on the results found, a relationship is established, discussed and improved between the Tear srength and the shrinkage denim fabric. To improve the PCA results, the polonomial regression analysis was applied to develop a good and significant model relating the Tear srength in the weft direction and the shrinkage weft direction denim fabric as function of the input parameters (types of fabric and washing types). Hence, the model regression equation was applied to evaluate and analyse the PCA results. Indeed, the coefficient of regression value is 0.7194 which seems fruitful and accurate for industrialists. The implementation of the regression equation in practice to estimate the mechanical properties through the shrinkage rate has shown that the error values are low. It leads manufacturers to eliminate the test of mechanical properties that remain as destructive tests. Moreover, according to results obtained, it may be concluded that prediction still accurate through the shrinkage test which is an inevitable test. Even thought, these results can bring a huge gain for the garment wash industries.

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