THE INFLUENCE OF INDUSTRIAL FINISHING TREATMENTS AND THEIR SUCCESSION ON THE MECHANICAL PROPERTIES OF DENIM GARMENT

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Abstract:

The principal aim of this work is to study the effect of matter, types of launderings (stone wash, enzyme wash, mixed wash and rinse), special treatments applied during the manufacturing process of garment washing (brushing, sanding, resin-treatment, bleach-treatment, permanganate-spray and softening) and their succession on the fabric mechanical properties: Tear strength (T. S) and Breaking strength (B. S). The results show that all these treatments, applied to obtain more worn appearance and aged look for garment has decreased the mechanical properties. Moreover, the resin- treatment is the most aggressive for cloths in the set of the special treatments. In fact, whatever the following washing process is stone washing or mixed washing, the finishing resin-treatment destroys the matter and reduces a lot the mechanical resistance. Thus, we proved that in the case of washed denim fabric, it is advisable to avoid the line of succession of treatments containing the resin-treatment and mixed washing process.

Key words:

Finishing treatment, effect of matter, laundering, fabric, mechanical properties

Introduction

The treatment of the prepared garment, and 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 shade and the fabric mechanical properties. The application of these treatments (brushing, sanding, bleach, spray…etc.) and their succession 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. For this reason, the survey of the effect of these treatments on the mechanical properties is asked, to testify to what extent (limit) the fabric support the succession of the treatments in order to choose the most suitable line of finishing obtaining the wanted shade while avoiding an important deterioration of matter.

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, Edge Abrasion [4]) and no studies are carried on industrial conditions.

Thus, the purpose of this study is to determine 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. A rigorous statistical analysis is established to obtain a model describing the variation effect of studied parameters and their interactions.

Table 1. Fabric Specifications.

Fabric code	Composition	Mass / area (g/m²)	Fabric finishing
T1	95% cotton, 5% elastane (On weft)	350	mercerized
T2	100% cotton	350	not mercerized
T3	100% cotton	350	mercerized
T4	100% cotton	421	not mercerized

Table 2. Dyeing of warp yarn.

Fabric code	Dyeing of warp yarn*	Concentration of dyeing bath of Indigo(g/l)	Concentration of dyeing bath of sulfur (g/l)	Colors of sulfur
T1	Seven Indigo baths	0.46	--	--
T2	One sulfur bath and seven Indigo baths	0.61	C1 : 1.15 C2 : 3.50 C3 : 5.00	C1 : Black greenness C2 : Blue redness C3 : Green yellowness
T3	One sulfur bath and seven Indigo baths	0.61	C1 : 1.15 C2 : 3.50 C3 : 5.00	C1 : Black greenness C2 : Blue redness C3 : Green yellowness
T4	One sulfur bath and seven Indigo baths	0.45	C1 : 25 C5 : 25	C1 : Black greenness C5 : Clear Blue redness

Table 3. Experience plan.

Factors/ Levels	Type of fabric	Special Treatments	Washing Types	Bleach - treatment	Permanganate- Spray	Cationic softening
1	T1	Brushing (Br)	Stone (S)	Bleach (B)	Spray (S)	Soften (A)
2	T2	Sanding (Sa)	Mixed (M)	No bleach(NB)	No spray (NS)	No soften (NA)
3	T3	Resin- treatment (Re)	Enzyme (E)	-	-	-
4	T4	-	Rinse (R)	-	-	-

Experimental method

Four types of Denim fabrics were selected for this study. The selected fabrics differ by their weight (medium weight fabric and heavy weight fabric), the fabric finishing process (mercerized fabric and no mercerized fabric) and the matter composition (cotton and cotton elasthane). The fabrics were finished with the same line of finishing (mercerization, skewness, sanforization). A summary of the fabric properties used in this study is given in Tables 1and 2.

The treatments have been done on trousers manufactured from these four fabrics according to a well definite experience plan [5] as shown for Table 3.

So each sample was finished by different processes of washing and some special treatments before ending with a cationic softening as shown for Table 4.

All types of washing start with a preparation and end by a soaping, softening, wring and drying. The measures of Tear strength (T. S) [6] and Breaking strength (B. S) [7] of apparel have been achieved after every treatment.

We completed our work by one statistical study while using the factorial experience plan presented in the table 3. The choice of these treatments (factors) as well as their mode, drives us to make a factorial experience plan (complete) with only two process of washing (stone wash and mixed wash)* 4 x 3 x 2 x 2 x 2 x 2 [8], containing 192 lines or experiences. This plan is repeated 3 times, we obtain a factorial plan of 576 experiences. The Enzymatic wash and the rinse wash not be used in the experience plan because industrially we can not used all this these treatments with these two washing process.

Statistics generated by " MINITAB " were used to investigate the differences in tear strength and breaking strength for the most important parameters of finishing garment washed denim.

Table 4. Conditions of finishing treatments.

Treatments	Conditions
Sanding (Sa)	Nature : manual with gun Type of sand: Contains at least 5% of SiO2 Pressure = 5 bars Angle of attack = 45° Number of passage = 3
Brushing (Br)	Nature : automatic (robot) Rotational speed : 120 tr/mn Linear Speed of the brushes : 20 m/mn
Resin- treatment (Re)	Nature of product : DMDHDEU Concentration : 25% Pulverization : 5ml of resin / 1kg of merchandise
Permanganate- Spray (S)	Nature of product : potassium permanganate Concentration: 50 to 65 ml for a surface of (0,2m²). Distance of pulverization : 40 to 50cm Pressure = 2,5 bars Number of passage = 3
Bleach (B)	Product : 6,5 ml/l of gavel water of (12° chlorinate)
Stone washing(S)	Report of the bath = 1/5 Temperature = 5O°C Time of washing = 45mn Stone : new stones and worn-out stones (80kg for a load of 140 trousers)
Enzyme washing (E)	Report of the bath = 1/5 Temperature = 5O°C Time of washing = 45mn Enzyme : acidic Enzyme (pH = 5), 800g of enzyme for a load of 80kg of the merchandise
Mixed washing (stone + enzyme) (M)	Report of the bath = 1/5 Temperature = 5O°C Time of washing = 45mn Enzyme : acidic Enzyme (pH = 5), 800g of enzyme for a load of 80kg of the merchandise Stone : new stones and worn-out stones (20kg for a load of 140 trousers)

Results and discussion

Physical survey

The influence of types of laundering

To investigate the effect of types of laundering, current treatments frequently used in denim manufactures (stone washing, enzyme washing and mixed washing) are chosen. Tear strength and Breaking strength evolution after washing treatments is shown in Figure 1.

This figure illustrate that the decrease of mechanical resistance evolve in the same way for all cloths. The loss of resistance is important for the mixed process and it can reach 56% in warp direction and 45% in weft direction (Figure 1. b.). The rinse washing is the least degrading matter; so the decrease of mechanical resistance is about 21.5% in warp direction and 10% in weft direction (Figure 1. a.).

For the different garments, the warp yarns are affected markedly and are more weakened than the weft yarns for the different finishing treatments. Indeed, the weave of the fabric used is a 3/1 twill, so the effect of abrasion is more concentrated on warp yarns than weft yarns. In fact, when fabrics are laundered

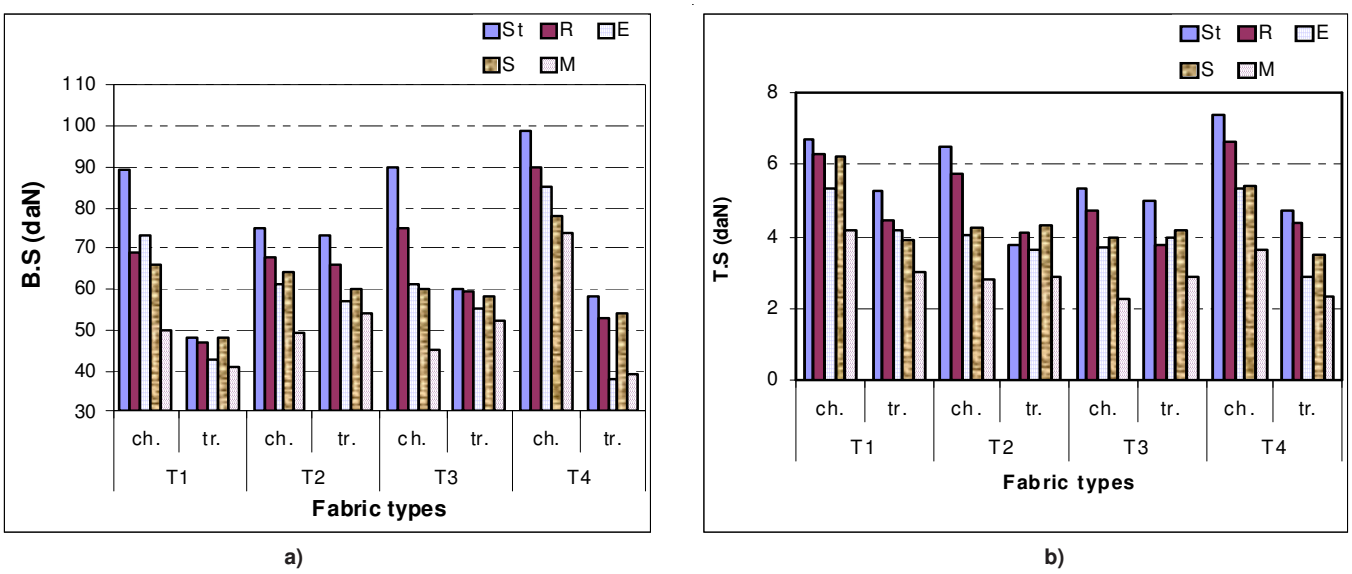

Figure 1. Evolution of the T.S and the B.S according to different types of laundering.

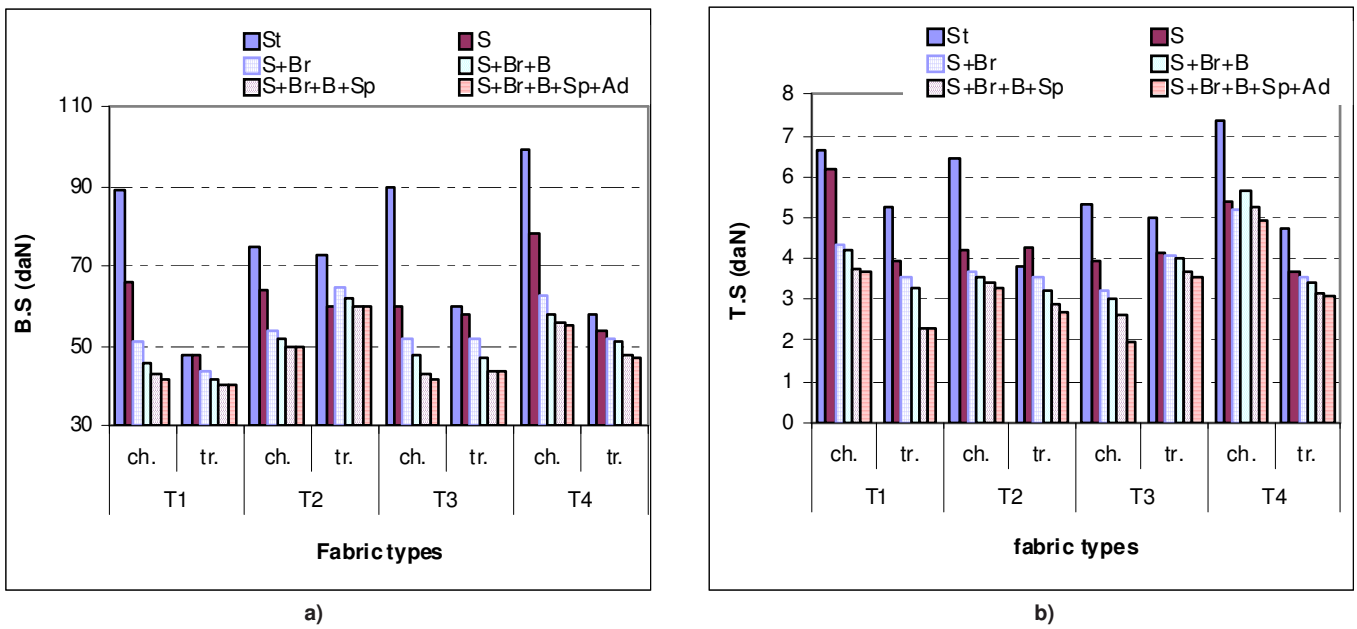

Figure 2. Evolution of the T.S and the B.S according to the succession of the treatments (brushing and a stone washing).

with stone or enzyme wash, the surface fibres are aggressively removed from the fabric surface by the stone or enzyme action thereby lower yarn surfaces can be worn away further. If the stones and enzyme are combined in the same laundering as in the mixed wash, the fibre's degradation become more important and causes an intensive decrease of mechanical properties.

Moreover, the matter is more damaged by the enzyme washing comparatively with the stone washing. In fact, the enzyme damages the cellulose, on the link 1, 4 β -glucosique of the cellulose molecule [9] [10]. The hydrolysis of this link breaks the molecule in several pieces, which can be themselves divided. Consequently the mechanical properties are greatly reduced.

On the other hand, the mechanical properties of the treated apparels are influenced by the fabric properties. In fact when comparing T1 and T3 properties, an enhance on the TS and BS are detected with the apparels made by the T1 fabric containing 5% of elasthanne. Moreover, when using a heavy fabric as the T4 one, which have the strongest mechanical properties, its TS and BS values are as affected as the other fabrics by the finishing treatments.

The influence of the special treatments

The Application of special treatments (Brushing, Sanding, and resin-treatment) has been done on untreated garments before stone or mixed washing.The T.S and B.S evolution after washing treatments is shown in Figures 2 and 3.

These figures illustrate that, after the different treatments, the measured mechanical properties of the different samples evolve with the same way for all cloths. Moreover, the loss of the T.S (Figure 3a) and the B.S (Figure 3b) varies in large limits according to the applied treatment: with T2 fabrics, it can reach 50% and 33% respectively in warp direction and 22% and 26% in weft direction when using a mixed (stone and enzyme) washing process with apparels beforehand treated with the crosslinking resin.

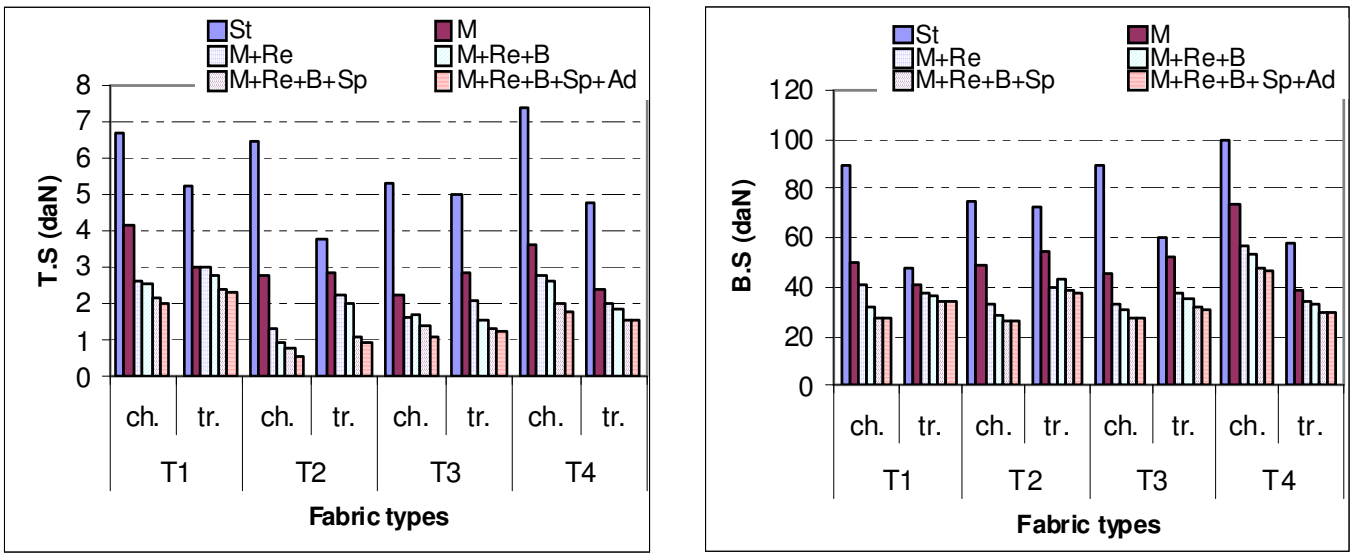

Figure 3. Evolution of the T.S and the B.S according to the succession of the treatments (resin-treatment and a mixed washing).

The brushing treatment weakens the matter. The main reason of this affectation is related to the fibre removing action of the brushes' hair from the fabric surface. This weakening can reach for T2 fabric in warp direction, 10% for the T.S (Figure 2b) and 17% for the B.S (Figure 2a). In the same way, the sanding treatment decreases mechanical resistance (T.S and B.S) with the same size of brushing treatment.

The resin-treatment is the most degrading treatment of the mechanical properties (approximately T.S and B.S are reduced to a half (Figure 3). The main reason of the loss of resistance is related with the acidic catalysis of the condensation polymerization as well as the degree of reticulation and the immobilization of the amorphous and flexible zones in the fiber, by the transverse links of the cellulose cotton that prevents the alignment of the molecular chains and crystallites in the extension direction.

By comparison with the fiber that do not have a transverse links (non treated with the reticulate resin), tension is transmitted for a little number of chains, and the structural elements of the fiber (molecular chains and fibrillation) submitted for a mechanical solicitation cannot manage by a mutual fiber slippage in order to resist together and at the same time. The rupture intervenes successively in the less numerous elements and in which the load is raised [11].

The bleach-treatment, the permanganate-spray and the softening treatments after different launderings of garment decrease progressively the mechanical resistance. Indeed, we notice that the bleach-treatment weakens the T.S, of 29% for T2 fabric in warp direction (Figure 3a) and the B.S respectively of 12% (Figure 3b) because the important oxidant reaction by the water of gavel [12]. In our survey, we use a half - bleach (concentration of water of gavel is 6, 5 ml/l). The sample will be affected more if we used a (hard bleach), but this last type of bleach-treatment is followed by a remarkable decrease of the mechanical resistance.

The permanganate-spray is to pulverize on the fabric a solution of potassium permanganate. This solution reduces a lot the T.S and the B.S in the T2 fabric, this loss is respectively 11% and 44% in warp direction. In the same way we notice that the permanganate-spray and the bleach-treatment weaken the mechanical resistance with a similar degree for the T.S but this degree is more intense for the B.S when the sample is treated with permanganate-spray treatment.

The influence of the succession of special treatments

While choosing a line of succession of finishing treatments, we can notice for the different types of fabrics. The T.S and the B.S decrease continuously up to five times after ending the finishing treatments. The decrease of T.S and the B.S values is due to the high level of mechanical abrasion generated progressively on the fabrics by the succession of the washing (stone or mixed) and mechanical special treatments (brushing or sanding) and the chemical action of the enzyme and chemical special treatments (bleach or spray).

This reduction of the T.S (Figure 4a) and the B.S (Figure 4b) for T2 fabric in warp direction is respectively of 50% and 33% for the line of the treatments containing a brushing and a stone washing. While with the same treatment succeed with a mixed washing, the reduction of the T.S and the B.S is respectively in warp direction 62% and 48%. The mixed washing destroys the matter more than the other processes because there are chemical and mechanical effects, which cause a more important deterioration of matter with this type of process.

Figure 4 shows that:

- The finishing resin-treatment with any process of washing (stone washing or mixed washing) destroys the matter and reduces enormously the mechanical resistance.
- The line of succession of treatments containing the resin-treatment and mixed washing process is the line in which the fabric loses a lot of the mechanical resistance.
- The line of the treatments that contains a brushing and a stone washing is the least degrading line for the mechanical properties.

Statistical study

Statistics generated by " MINITAB " were used to investigate the effect of type fabric, washing type, special treatments, bleach, spray and softening on the mechanical properties; Tear strength (warp direction), Tear strength (weft direction),

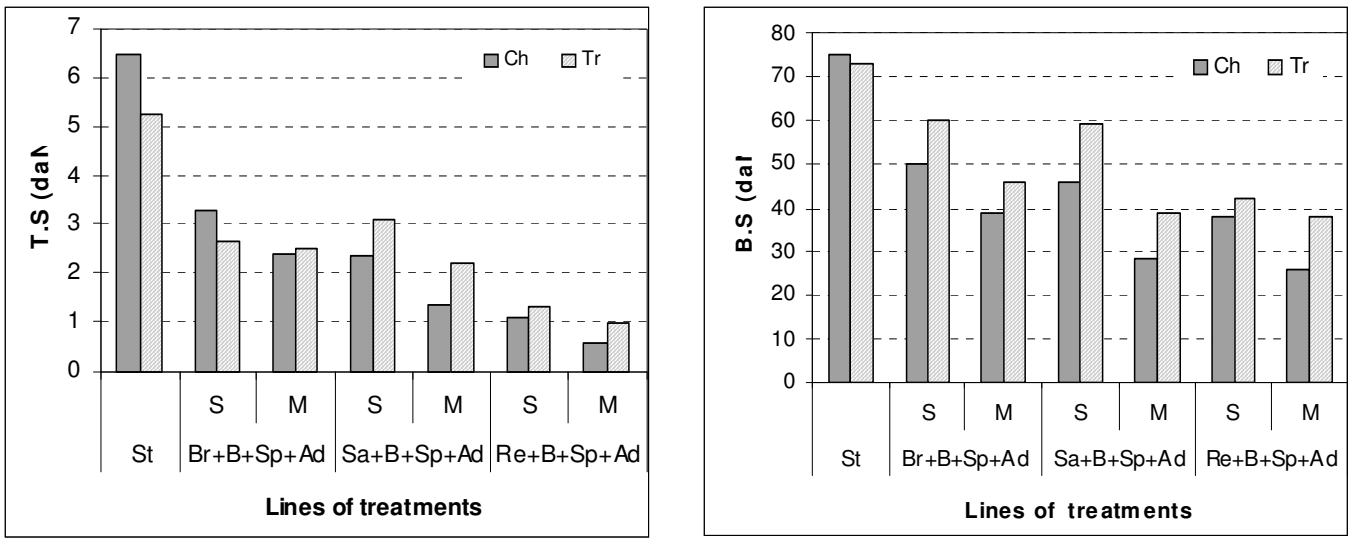

Figure 4. Comparison of the T.S and B.S according to the lines of the treatments for T2 fabric.

Breaking strength (warp direction) and Breaking strength (weft direction). The choice of these treatments (factors) as well as their mode, drives us to make a factorial experience plan (complete) (Table 3) with only two processes of washing (stone wash and mixed wash)* 4 x 3 x 2 x 2 x 2 x 2 (Vigier, M., 1991), containing 192 lines or experiences. Through repeating this plan 3 times, we obtain a factorial plan of 576 experiences.

The main effect, the interaction plot and the Analysis of variance (ANOVA) were used to determine the presence of significant differences of treatments.

The statistical results showed:

Justification of the model

By the test of the adjusted regression coefficient, the model of each response (Tear strength (warp direction), Tear strength (weft direction), Breaking strength (warp direction) and Breaking strength (weft direction)) is justified because he presents a regression coefficient very near of 1 (Table 5).

Table 5: Result of the interrelationship test

Responses	Regression coefficient
Tear strength (warp direction)	0.9506
Tear strength (weft direction)	0.9119
Breaking strength (warp direction)	0.9517
Breaking strength (weft direction)	0.9050

Analysis of the main effects plots

The main effects plot represents the averages of the answers for every level of every parameter, with the tracing of a reference line the global average of the answer information. This diagram is essentially used to compare the importance of the main effects of the different parameters; it is a first classification of the different treatments used in garment washing Denim according to their respective main effects on the final mechanical properties of garment.
Figure 5 shows that the type fabric, washing type, special treatments, bleach, spray and softening have a very important effect on T.S and B.S. The softening treatment has negligible effect on these two mechanical properties.

These results are completely in conformity with the experiences results where we showed that these treatments weaken the mechanical properties and their succession damages matter a lot.

Analysis of the interaction plot

The interaction diagram is a representation of the answers information averages for every treatment level. The level of the second treatment remained constant. This diagram is useful to judge the presence of interaction. An interaction is present if the answer for a treatment level depends on/or the other treatment levels. In a diagram of the interaction, some parallel lines indicate the absence of interaction [13]. More the lines depart of the parallel; more the degree of interaction is raised. This diagram informs us on the type of model to consider in the analysis of variance.

Figure 6 shows that there is interaction in each response:
T.S (wa_D): Interaction between [TxTs], [TxD] and [BxS]
T.S (we_D): Interaction between [TxTs], [TxD], [TsxS], [DxB] and [BxS]
B.S (wa_D): Interaction between [TxTs], [TxD], [TxB], [TsxD], [DxB] and [BxS]
B.S (we_D): Interaction between [TxTs], [TxD] and [TsxD]

This result is going to help us on the model to consider, so it is advisable to complete study by the analysis of variance.

Analysis of the variance

The analysis of variance is the most important test in this survey since it is going to permit us to judge if the effect treatments on the measured answer (T.S (warp direction), T.S (weft direction), B.S (warp direction) and B.S (weft direction)) are statistically significant [14] [15]. This test consists to calculate a statistical F from the coefficients of the established model and then to compare it to statistical tables of snedecor law [16], and from F we can calculate another P statistic (Table 6).
If P < 1%: then we say that the difference is highly significant.
If 5% < P < 1%: then we say that the difference is significant.
If P > 5%: then we say that the difference is not significant.

Analysis of variance showed that the matter, launderings and special treatments have a significant effect (Table 7) on mechanical properties. The legend of the table 7 is shown of table 8.

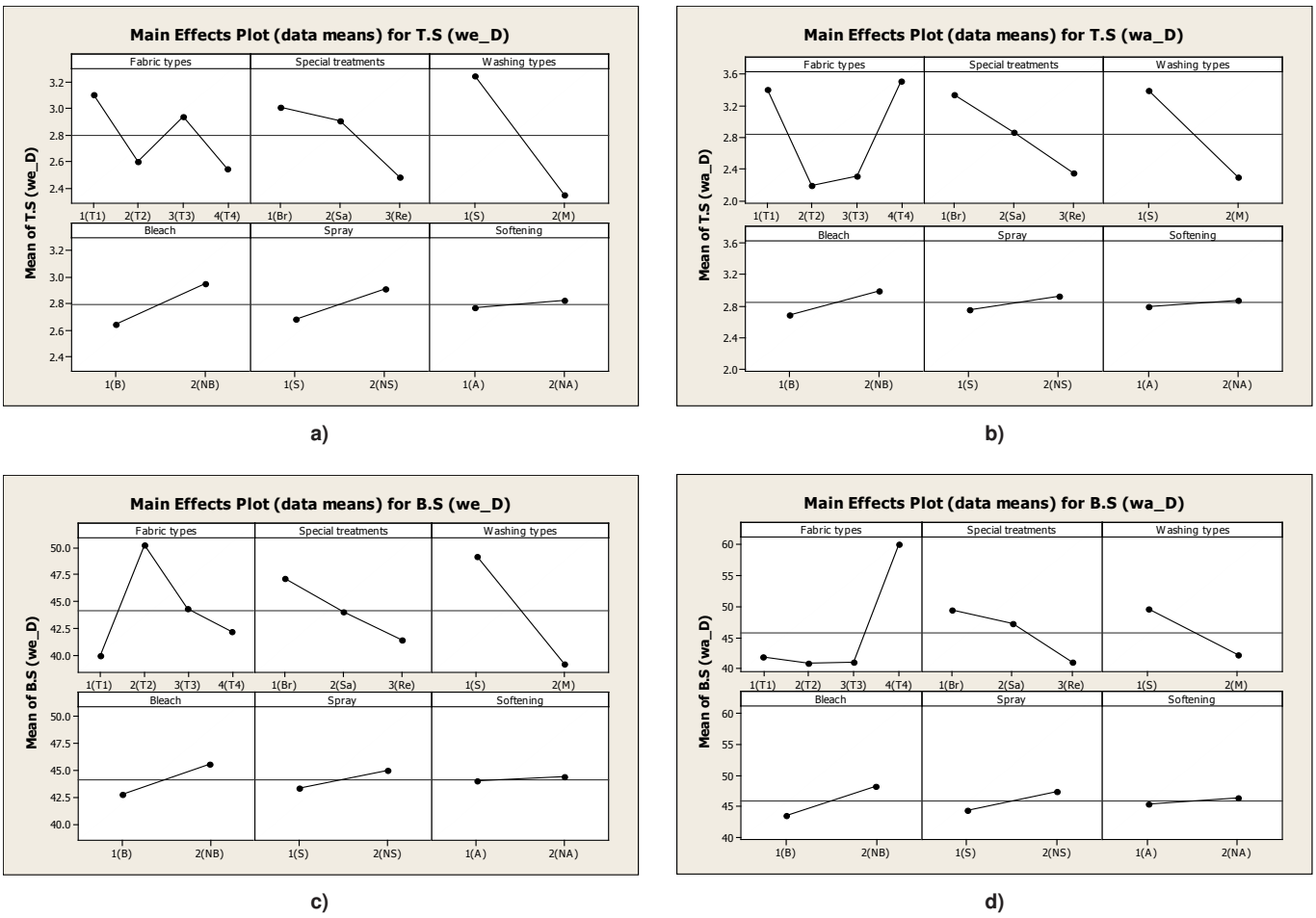

Figure 5. Graphic of the main effects for T.S (warp direction), T.S (weft direction), B.S (warp direction) and B.S (weft direction).

Table 6. Results of analysis of the variance.

Parameters	T.S (wa_D)		T.S (we_D)		B.S (wa_D)		B.S (we_D)	
	F	P	F	P	F	P	F	P
T	487.18	0.000	76.70	0.000	738.25	0.000	160.37	0.000
Ts	321.14	0.000	109.07	0.000	228.05	0.000	82.65	0.000
D	1163.91	0.000	852.12	0.000	428.09	0.000	808.42	0.000
B	98.09	0.000	94.10	0.000	211.93	0.000	59.88	0.000
S	27.44	0.000	55.58	0.000	68.08	0.000	21.82	0.000
A	4.83	0.029	3.13	0.079	4.84	0.029	1.67	0.198
T x Ts	36.20	0.000	16.17	0.000	10.18	0.000	15.16	0.000
T x D	13.18	0.000	130.72	0.000	77.54	0.000	62.00	0.000
T x B	0.96	0.415	2.09	0.103	4.53	0.005	0.14	0.938
T x S	1.22	0.306	0.14	0.935	1.68	0.174	0.01	0.998
T x A	0.26	0.851	0.09	0.966	0.36	0.784	0.02	0.997
TS x D	1.99	0.140	4.39	0.014	33.77	0.000	10.71	0.000
TS x B	0.37	0.694	1.99	0.140	2.09	0.128	0.98	0.377
TS x S	0.87	0.419	5.15	0.007	1.33	0.268	0.20	0.021
TS x A	0.19	0.824	0.06	0.945	0.49	0.610	0.16	0.851
D x B	0.04	0.835	4.31	0.010	8.95	0.003	1.17	0.282
D x S	0.11	0.743	6.30	0.013	0.98	0.323	0.36	0.552
D x A	0.25	0.619	0.44	0.507	0.17	0.677	0.02	0.902
B x S	13.71	0.000	16.52	0.000	18.55	0.000	5.28	0.028
B x A	0.31	0.578	0.64	0.426	0.63	0.430	0.51	0.476
S x A	0.46	0.500	0.07	0.791	0.14	0.713	0.02	0.892

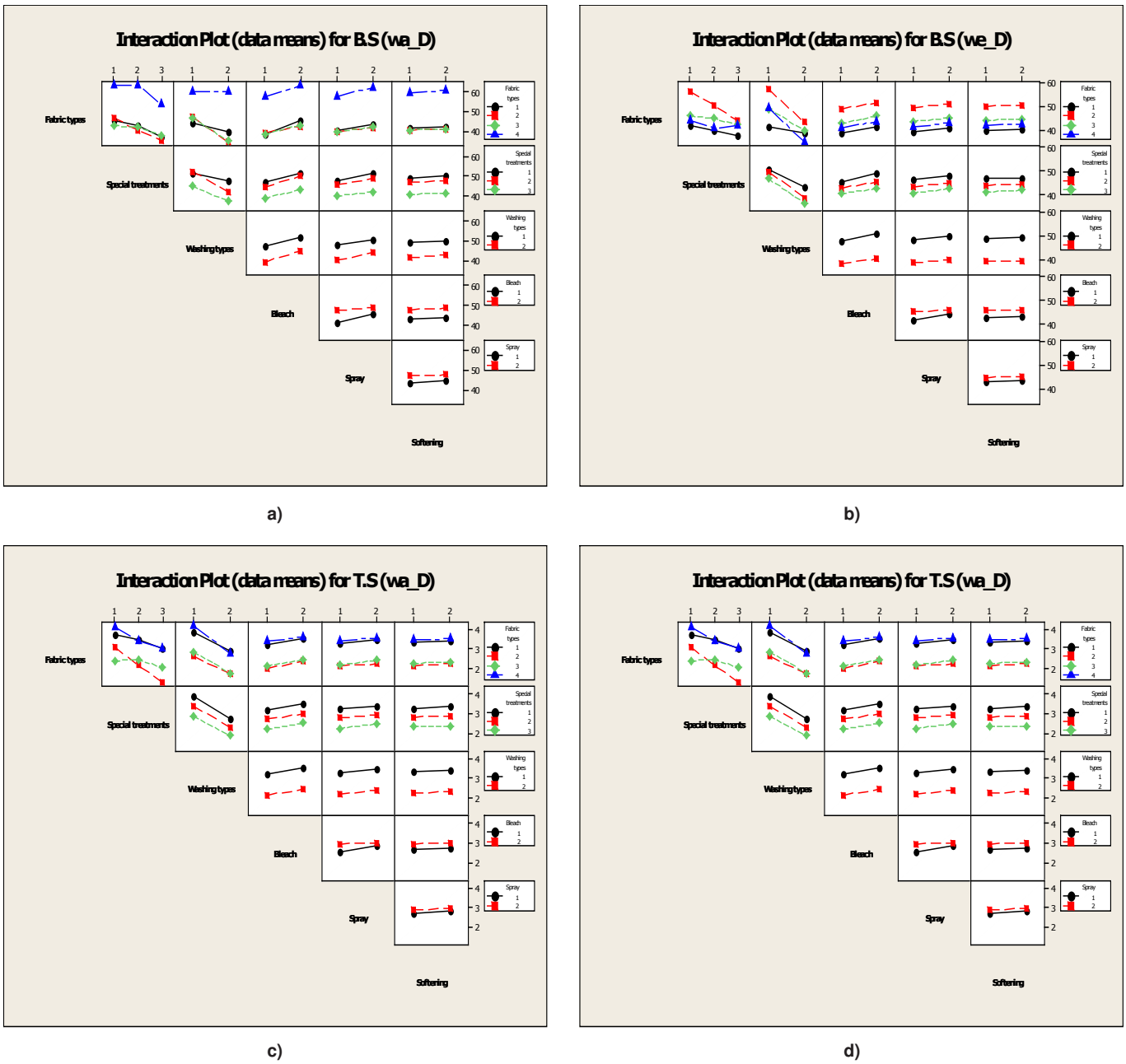

Figure 6. Graphic of the interaction plot for T.S (warp direction), T.S (weft direction), B.S (warp direction) and B.S (weft direction).

Analysis of variance showed that the matter, launderings and special treatments have a significant effect (Table 7) on mechanical properties. We summarize the results of the statistical analysis in the established interrelationship equations between the different treatments and their interactions. There equations represents the effect statistically significant effect of every studied parameter ($p < 5\%$).

T.S (wa_D) = [T] + [Ts] + [D] + [B] + [S] + [TxTs] + [TxD] + [BxS]
T.S (we_D) = [T] + [Ts] + [D] + [B] + [S] + [TxTs] + [TxD] + [TsxS] + [DxB] + [BxS]
B.S (wa_D) = [T] + [Ts] + [D] + [B] + [S] + [TxTs] + [TxD] + [TxB] + [TsxD] + [DxB] + [BxS]
B.S (we_D) = [T] + [Ts] + [D] + [B] + [S] + [TxTs] + [TxD] + [TsxD]

Confrontation of the statistical model and the physical survey
The statistical study showed that the treatments achieved during garment washed denim have a highly significant effect on the mechanical properties decrease (Tear strength (T. S) and Breaking strength (B. S)). Moreover the presence and the importance of the interactions between the different treatments (washing type, special treatments, bleach, spray and softening) have a significant effect also. These statistical results are confirmed by the physical survey where we showed that the washing type mixed or stone, the special treatments (brushing, sanding or resin-treatment), the bleach-treatment and the spray decrease a lot the Tear strength (T. S) and the Breaking strength (B. S). In the same way we showed that the succession of the treatments damages too much matter and the line of succession of treatments containing the resin-treatment and mixed washing process is the line in which the fabric loses more than 90% in warp direction. This reduction risks to breaking fabric in the treated zones.
In conclusion we can say that the statistical model is confirmed by the physical survey.

Conclusion

The statistical and physical study of the mechanical properties of tear strength and breaking strength of garments after every finishing treatment showed that:

Table 7. Summing up of the results analysis of the variance.

Parametres	T.S (wa_D)	T.S (we_D)	B.S (wa_D)	B.S (we_D)
T				
Ts				
D				
B				
S				
A				
T x Ts				
T x D				
T x B				
T x S				
T x A				
TS x D				
TS x B				
TS x S				
TS x A				
D x B				
D x S				
D x A				
B x S				
B x A				
S x A				

Table 8. Legend of Table 7.

Less main effect	No much main effect	Much main effect

- The washing process, the special treatments and their succession on the apparel reduce the mechanical properties; this reduction can be seen in warp yarns more than weft yarns.
- The resin-treatment is the most degrading treatment of the mechanical properties for Denim garment.
- It is advisable to avoid the line of succession of treatments containing the resin-treatment and the mixed washing process.
- To obtain an aged look for the garment, it is advisable to study mechanical resistance and cloth shade to choose the optimum line of finishing (less decrease of mechanical properties and increasingly whiteness).

References:

1. *L. Higgins, S.C. Anand, D.A. Holmes, M.E. Hall, and K. Underly; Effect of various Home Laundering Practices on the Dimensional Stability, Wrinkling, and Other Properties of Plain Woven Cotton Fabrics. Part I: Experimental Overview, Reproducibility of results, and Effect of Detergent; Textile Res. J. Vol 73; April 2003; pp 357-366.*
2. *L. Higgins, S.C. Anand, D.A. Holmes, M.E. Hall, and K. Underly; Effect of various Home Laundering Practices on the Dimensional Stability, Wrinkling, and Other Properties of Plain Woven Cotton Fabrics. Part II: Effect of Rinse Cycle Softener and Drying Method and of Tumble Sheet Softener and Tumble Drying Time; Textile Res. J. Vol 73; May 2003; pp 407-420.*
3. *Jiri Militky and Vladimir Bajzik; Influence of washing/ironing cycles on selected properties of cotton type weaves; International Journal of clothing Science and Technology; Vol 9; No. 3, 1997; pp 193-199.*
4. *Ayanna Card, Mary Ann Moore and Mary Ankeny; Garment washed jeans: impact of launderings on physical properties; International Journal of clothing Science and Technology; Vol 18; No. 1, 2006; pp 43-52.*
5. *R. Phan-Tan-Luu: Methodology of the experimental research, Edition Euskatel Estatistika; Spain; 1993; pages 132-134.*
6. *Norme ASTM D 1424-83 (Elmendorf) : An American Standard pour la mesure de la résistance à la déchirure; page 83.*
7. *Norme ASTM D 5034-90 (Grab) : An American Standard pour la mesure la résistance à l'arrachement; page 90.*
8. *M.VIGIER. Pratique des plans d'expériences, méthodes Taguchi et compléments, Paris : les éditions d'organisation, 1991.*
9. *Marek WELTROWSKI. Traitements enzymatiques : actualités et perspectives ; L'industrie textile, N° 1261, janvier 1995, p 52-59.*
10. *Gitte L. PEDERSEN, Garrett A. SCREWS JR. Donna M. CEDRONI. Le biopolissage des articles cellulosiques; L'industrie textile, N° 1244, juin 1993, p 53, 54 et 55.*
11. *I.T.F. (InstitutTextile de France). Ennoblissement des fibres cellulosiques, III Les Apprêts, la réticulation à l'état mouillée ; pages 50-55.*
12. *I.T.F. (InstitutTextile de France). Le blanchiment des fibres cellulosiques ; page 30, 31 et 32.*
13. *C.R. HICKS. Fundamental concepts in the design of experiments, 3rd Ed CBC College Publishing, 1982.*
14. *G. A. MILIKEN and D. E. JOHNSON; Analysis of Messy Data, Vol, 1: Designed Experiments Van Reinhold, 1984.*
15. *P.R. NELSON. A Comparison of Sample seizes for the analysis of means and analysis of variances. Journal of Quality Technology, 1983, N° 15, pages 33-39.*
16. *R.A. OLSHEN. The conditional level of the F-test, Journal of the American Association, 1973, N° 68, pages 692 - 698.*

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