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EFFECT OF FRICTION PARAMETERS ON THE RESIDUAL BAGGING BEHAVIOR OF DENIM FABRICS

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ABSTRACT

This research focuses on the yarn-to-yarn and metal-to-fabric friction effects on the residual bagging behavior expressed by residual bagging height, volume and recovery of some denim fabrics. The results show, that both residual bagging height and residual bagging volume, which is determined using image analysis method, are significantly affected due to the most influential fabric parameter variations, the weft yarns density and the mean frictional coefficients. After the applied number of fatigue cycles, the findings revealed that the weft yarn rigidity contributes on fabric bagging behavior accurately. Among the tested samples, our results show that the elastic fabrics present a high recovery ability to give low bagging height and volume values.

KEYWORDS

Denim fabric, yarn-to-yarn friction, metal-to-fabric friction, residual bagging height, bagging recovery.

1. INTRODUCTION

Bagging is a three-dimensional residual deformation, seen in used garments, which causes deterioration in the appearance of the garment. These unaesthetic parts of garment appeared on elbows, knees, pockets, hips, and heels (Sengoz, 2004). Therefore, many researchers are interested in this subject. Indeed, most works have focused on characterization of the bagging fabric behavior using different methods (Zhang et al., 1999a,1999b, 2000a, 2000b, Abghari et al. 2004; Hassani, Zadeh, 2012; Jaouachi (2013a); Jaouachi (2013b); Jaouachi et al. 2010, 2011). However, the problem is that there is not enough information available to evaluate the effect of the yarn-to yarn friction on the residual bagging behavior. Friction is an important parameter which has been studied differently on the textile fields. Different friction phenomena can exist such as the friction inter-fibers, inter-yarns and inter fabrics. Matukoni (Matukoni et al., 1999) studied some characteristics of textile products, such as touch and felt properties, softness, and their contributions on its friction behavior. The interactions between yarns during process transformation, caused friction and, hence, determine different mechanical properties of the woven and knitted fabrics, such as: tensile, compression, and shear characteristics. Svetnickienė and Čiukas (Svetnickienė and Čiukas, 2006) found that friction coefficient of the yarn depends on the rigidity and the tension of needle yarn in knitting machines. In addition, referring to literature, some researchers have dealt with the yarn-to-yarn friction. Liu (Liu et al., 2004) found that there is a friction between warp and weft yarns at every crossover. Moreover, their results show that the yarn-to-yarn friction is the main cause which is able to determine the shear and the

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formability properties of woven fabrics. Allaoui (Allaoui et al., 2012) presented a good relationship between the fabric-to-fabric friction and yarn-to-yarn friction one. However, the value of the yarn-to-yarn friction coefficient is lower than the average value of the fabric-to-fabric friction coefficient. Thus, many studies (Grosberg, 1966, Behera, 2007; Rengasamy, Das and Patil, 2009) showed that both inter-yarns and intra-yarns frictions participate widely in the bending behavior. Until now, there is no work dealing with the yarn-to-yarn friction effects on the residual bagging behavior. In fact, Zhang (Zhang et al., 1997, 2000c) proved that a permanent fabric deformation is affected by both friction inter-fibre and creep. Their results showed that the behavior of bagged wool fabrics is function of frictional forces and fibre viscoelasticity behavior. Therefore, the present work aimed to investigate the effect of the yarn-to-yarn friction on bagging behavior of denim fabric.

2. METHODS AND MATERIALS

2.1. Fabric samples and characteristics

Different elastic and non-elastic woven fabrics, weave twill 3/1 pattern, were produced using the same experimental conditions. The warp yarn is a ring cotton yarn. However, the weft yarns have different components and are produced using three different spinning processes: rotor, ring-spun and open-end. Tables 1 and 2 show the mechanical and physical properties of the used yarns (especially weft yarns) and fabric samples respectively. According to the French Standard (Afnor, 1985), overall specimens are conditioned during 24 hours in the laboratory atmosphere. The size of each fabric specimen and yarns prepared to tensile test is as recommended by the French Standard (NF G07-003).

Table 1: Characteristics of the warp and weft yarn used to produce woven fabrics.

Yarn samples	Yarn count, Nm	Composition + spinning process	Twist (tpm)	Ultimate tensile strength (N)	Strain (%)	Tenacity (cN/tex)	Rigidity (N/m)
warp	12.5	100% CT$^{\alpha}$ (ring)	413	9.78	8.04	12.22	521
weft1	20	95%CT+5% Elast$^{\beta}$ (ring+ 78 dtex)	671	6.39	10.11	12.78	623
weft2	17	100% CT (Open End)	453	7.20	10.9	12.24	1067
weft3	17	100% CT (Open End)	524	8.08	5.49	13.74	1683
weft4	15	100% CT (open- end)	365	5.62	4.39	8.43	1801
weft5	20	95%CT+5% Elast Elast (ring+ 78 dtex)	671	6.39	10.11	12.78	623
weft6	20	71%CT+24% PES$^{\sigma}$+5% Elast Elast (ring+ 78 dtex)	342	5.78	5.18	11.56	1345
weft7	17	100% CT (Open End)	824	6.98	4.39	11.87	1810
weft8	28	95% TC$^{\eta}$ + 5% Elast Elast (ring+ 78 dtex)	412	3.82	4.35	10.70	713

$^{\alpha}$CT : cotton, $^{\beta}$ Elast : elastane, $^{\sigma}$ PES : polyester, TC$^{\eta}$: tencel.

Table 2: Main physical and mechanical properties of the tested denim fabrics.

Fabric ID	Weight (g/m^2)	Thickness (mm)	Weft density (picks/cm)	Warp density (ends/cm)	Ultimate tensile strength (N)	Breaking work (J)	Strain (%)	Weft Rigidity (N/m)
1	328	0.67	20.5	29.7	565.0	7.6	24.8	32537
2	352	0.74	17.0	28.2	757.5	11.2	33.2	33898
3	394	0.78	16.5	27.8	853.8	7.8	14.7	56249
4	372	0.74	22.0	29.4	810.3	9.8	24.3	41274
5	368	0.69	20.0	30.9	919.0	9.2	6.9	54822
6	323	0.65	19.0	31.8	568.5	9.0	30.7	23748
7	387	0.67	16.0	30.9	1071.9	11.2	17.9	67043
8	341	0.69	19.5	32.3	540.4	8.5	36.1	21393

To evaluate the abrasion of yarns composed the bagged fabrics, a Simulator Abrader Tester instrument was used (Figure 1). This instrument was developed by Jaouachi et al. (Jaouachi et al., 2011).

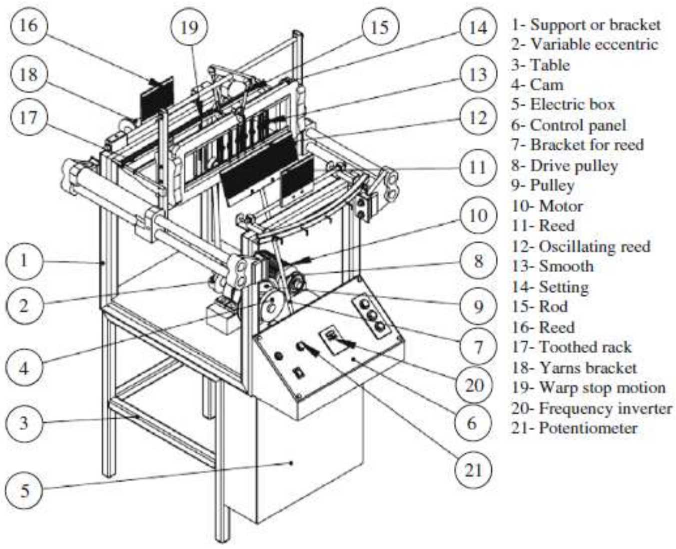


Figure 1: Similator Abrader Tester (Jaouachi et al., 2011)

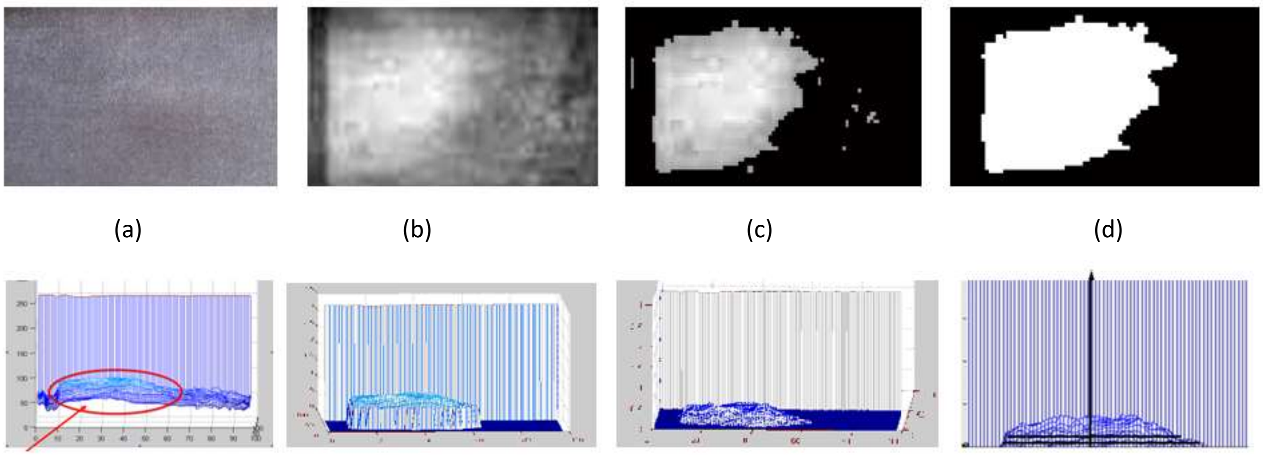
The number of cycles of abrasion reflects the friction between yarns. Thanks to the solicitations due to the abrasion yarn-to-yarn and yarn-to-metal, the fatigue of yarns is the result of the frictional forces between yarns. Before the breaking yarn, the abrasion cycle number was saved and then, the yarn rigidity was measured using a dynamometer type Lloyd. The average abrasion cycle values of each yarn sample correspond to 50 tests.

To measure and calculate the frictional forces generated by the conformator to the surface of denim samples, the Kawabata Evaluation System KES- FB4 (Kawabata and Niwa, 1991), was used. To simulate the impact of friction caused by the conformator to fabric during bagging test, the frictional coefficient (MIU) parameter values were saved. The KES- FB4 system is equipped by a hand feeling finger touch system to measure and evaluate the MIU frictional property of tested fabrics. This parameter is a property which can help to determine the residual volume behavior of woven fabric samples. The test is repeated 9 times to obtain an average value of the compression energy. Moreover, according to the French Standard NF G 07- 213 (AFNOR, 2001), bagging tester type *Sodemat* was used to measure residual bagging height and bagging recovery values (R_{bh} and B_{rec}). The bagging test and experimental conditions were described in previous works (Jaouachi, 2013a, 2013b). Each woven fabric sample should be maintained under hemispherical ball (conformator) during 5 hours. The applied steel ball load was deduced by using preliminary elongation test during 48h under a load of 300cN. To measure the residual bagging height (R_{bh}) and the residual bagging recovery (B_{rec}), a relaxation of 30 minutes, should be taken for the bagged denim samples. However, to evaluate the recovery property variation during relaxation time, values of this property were investigated and saved each five minutes.

2.2. Image analysis processing

To evaluate the residual bagging volume of denim samples, image analysis process was adopted and included capturing digitized images of bagged zones. Therefore, the procedure of evaluating bagging volume of denim fabric samples includes the capture of bagged zone digitized images of bagged zones, image processing of the digitalized images, and transforming digitized values in 3D distributions to recognize residual bagging volume, Rbv. During image processing, all technical parameters, such as the magnification value, the position, the brightness, and the angle of the light source, are adjusted and then kept the same to obtain suitable and comparative images.

Then, the captured images are transformed to digitized values. During image processing, overall suitable parameter values such as the magnification value, the position, the brightness, and the angle of the light source, are adjusted and then kept the same to obtain comparative images. After bagging test, the samples are captured using a digital camera (Figure 2a). Overall images (Figure 2b) are transferred into gray level (ranged from 0, referred to black color to 255 referred to white color) images which refer to a two dimensional light intensity function. The gray level distribution presented the 3D bagging volume appearance (figure 2c, 2d). Using *mesh* function on Matlab software, the images in 3D are obtained by conversion of those in 2D into gray scale level and returned into double precision (figure 2e, 2f, 2g, 2h). An uneven distribution of intensity in the image was occurred due to both the 3D deformation and the color of fabric texture. These intensity distribution values remained function of the fabric variation profile which modified the gray level over a certain spatial distance. Each sample was repeated 9 times to obtain mean residual bagging volume values.



(a) (b) (c) (d)

(e) (f) (g) (h)

Figure 2 : Image Analysis Steps

2.3. Principal Component Analysis (PCA)

The Principal Component Analysis (PCA) is a statistical method of description and reduction of studied parameters. Its goal is to find correlations between the data (inputs and outputs) and to represent the influence of the inputs/outputs. Besides, the PCA method amplifies subjectively the weight of certain parameters while it dampens others that are less relevant to output values (Jaouachi, 2012). The correlated parameters are grouped together inside the circle with radius 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 centre 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 be causes 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. Furthermore, the groups of variables which have symmetrically opposite direction relative to the horizontal axis are positively correlated. 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.

3. RESULTS AND DISCUSSION

Table 3 shows the different parameters characterizing residual bagging behavior (R_{bh}, R_{bv}, and B_{rec}) and frictional inputs (Wt_{rig} and Ab_{cy} and MIU parameters relative to tested weft yarns and denim fabric respectively). These properties are measured to evaluate the friction contribution on the bagging behavior on denim samples. Therefore, some relationships are found and discussed.

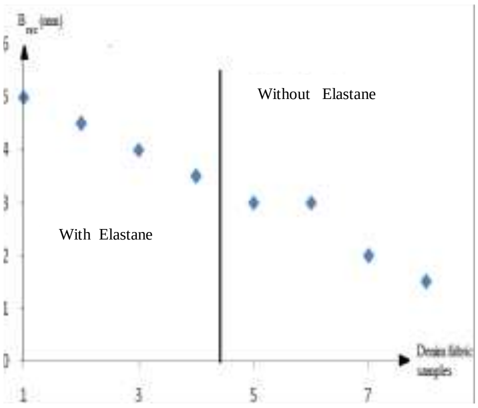
Table 3: Mean residual bagging and friction parameters relative to both analyzed yarns and fabrics.

Fabric structure	Fabric Identification	$^{\alpha}R_{bh}$ (mm)	$^{\beta}R_{bv}$ (mm^3)	$^{\mu}B_{rec}$ (mm)	$^{\nu}$MIU	$^{\Phi}Ab_{cy}$	$^{\omega}Wt_{rig}$ (N/m)
With Elastane	2	11.0	4282	50.0	0.162	2000	623
With Elastane	3	12.0	5464	4.5	0.160	2000	623
With Elastane	4	11.5	4610	4.0	0.160	1100	675
With Elastane	7	13.0	7874	3.5	0.155	1700	1067
Without Elastane	1	11.5	5312	3.0	0.157	1300	1683
Without Elastane	5	13.0	8100	3.0	0.155	1000	1801
Without Elastane	6	11.0	4549	2.0	0.154	1600	1810
Without Elastane	8	10.0	3585	1.5	0.170	2000	2101

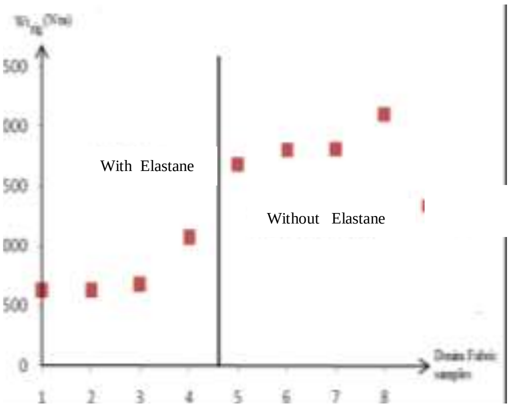
$^{\alpha}R_{bh}$: Residual bagging height, $^{\beta}R_{bv}$: Residual bagging volume; $^{\mu}B_{rec}$: Residual bagging recovery property; $^{\Phi}Ab_{cy}$: Represents the number of yarn abrasion cycles obtained using Abrader Tester; $^{\omega}W_{rig}$: Weft rigidity after yarn-to-yarn abrasion; $^{\nu}$MIU: Represents the frictional coefficient of the denim fabric obtained using KES system.

3.1. Effect of weft yarn rigidity on the residual bagging behavior

Figure 3a shows the difference between the recovery of bagged denim fabrics within and without elastane filament. The results show that the bagging recovery of elastic woven fabrics is lower than those without elastane filament. Regarding to the findings obtained, it may be concluded that woven fabrics within elastane filament give high recovery value. Hence, the quick return expressed by high recovery value, can be explained by the existence of elastane filament inside tested sample which encourages widely the elastic behavior of denim fabrics. Besides, this result is in a good agreement with Baghaei et al. (Baghaei et al., 2010) and Őzdil's findings (Őzdil, 2008). Indeed, they concluded that the recovery property of some elastic textile structures is affected by their viscoelasticity behavior, their mechanical properties of the fabric and the earlier mechanical steps of transformation such as mechanical cleaning, spinning and weaving process.



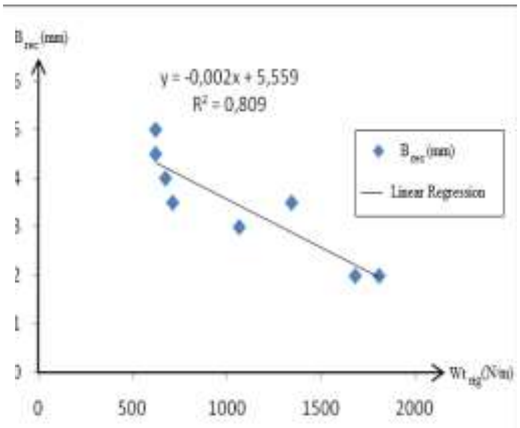
(a) Bagging recovery variations.



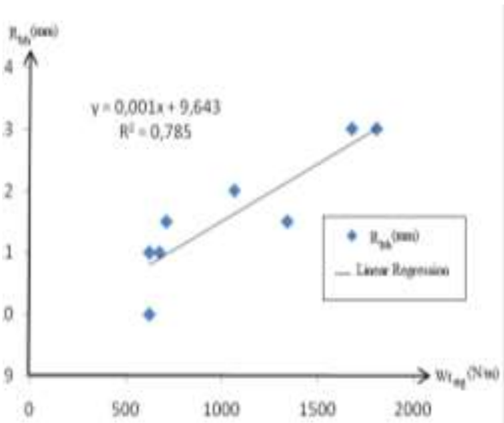
(b) Weft yarn rigidity variation

Figure 3: Bagging recovery and Weft yarn rigidity variation of tested denim fabrics

Figure 3b illustrates the difference between the weft rigidity of the different yarns of denim fabrics after abrasion test with and without elastane filament. The tested rigidity property value defines and reflects the friction between the weft yarns. Applying on each sample, the results show that the weft rigidity is correlated negatively with the bagging recovery and it doesn't depend on the yarn elasticity. Figure 4 shows good relationships between the bagging behavior (bagging recovery, B_{rec}, residual bagging height, R_{bh} and residual bagging volume, R_{bv}) and the weft abrasion rigidity (Wt_{rig}).



(a)



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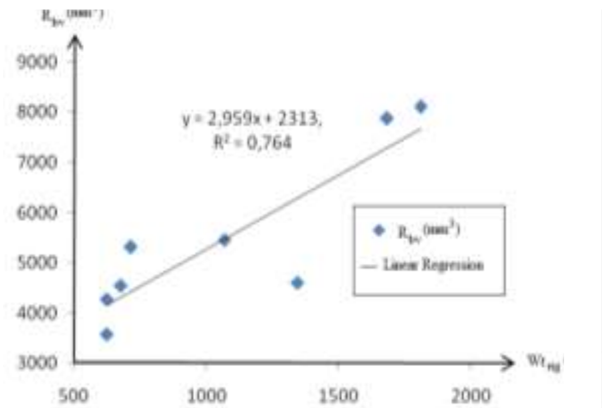


(c)

Figure 4: Effect of the weft yarn rigidity on the residual bagging behavior; (a) as a function of B_{rec}; (b) as a function of R_{bh}; (c) as a function of R_{bv} values.

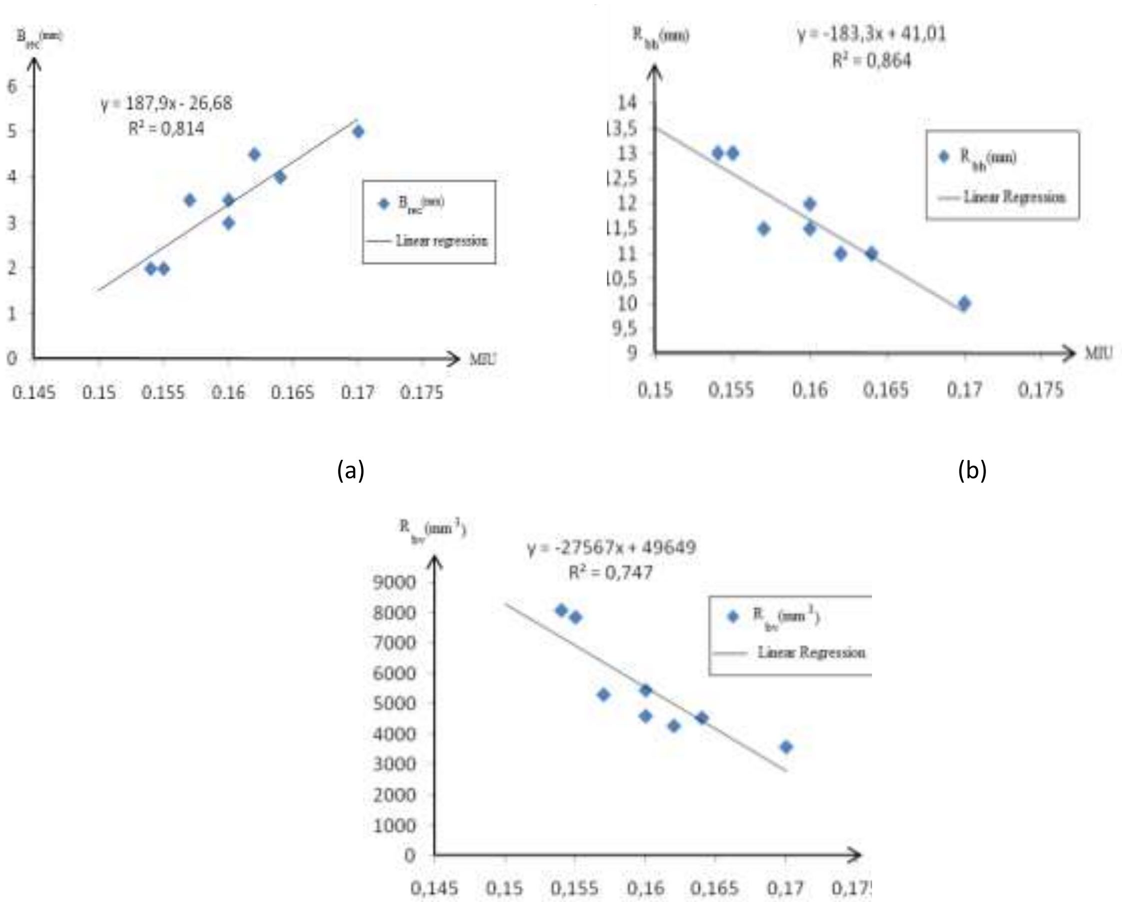
Indeed, referring to Figure 4a, there is a high relationship between the weft yarn rigidity and the bagging recovery. In fact, when the rigidity parameter increases, the bagging recovery property decreases. The coefficient of regression is equal to 80.9%. This value is close to 1 which encourages predicting the bagging recovery property in our experimental design of interest.
According to results shown in Figure 3b and 3c, the residual bagging volume and the residual bagging height increase with the increase of weft yarn rigidity. In fact, more rigidity as well as more frictional resistance which results in less recovery, thus increases both the residual bagging height and volume. This result is in good agreement with the Hossein and Sanaz's study finding (Hossein, Sanaz, 2012) applied to knitted fabrics. Recently, they have concluded that the fabric rigidity prevented the deformation resistance during the bagging test and caused the increase of residual bagging height. It is notable that good relationships were saved, the coefficients of regression values are equal to 78.5% for Rbh and to 76.4% for the Rbv (Figure 3). According to Figure 4, it may be concluded that the coefficients of regression values are acceptable and are ranged from 76.4% to 80.9% which indicate the high relevance and significance of the relationships between studied inputs (frictional parameters) and analyzed bagging properties. Thus, these results (Figure 4) allow us to predict the residual bagging parameters as function of friction yarn-to-yarn parameter basing on the weft yarn rigidity. So, the yarn-to-yarn friction effect is non neglectable and it remains a significant input parameter which contributes accurately to the behavior of the bagging denim fabric samples. Indeed, the yarn-to-yarn friction generates two studied frictional parameters such as the abrasion resistance and the weft rigidity after applied cyclic tests. These frictional inputs occurred during weaving steps such as during warp yarn beat-up or yarn shedding positions. In these critical zones, frictional stresses are high and the yarn's abrasion resistance, expressed by lifetime abrasion cycle numbers or weft rigidity after yarn-to yarn abrasion, is more affected by the weaving parameters and zones especially on the shedding position because it increases breakage rate (Jaouachi et al., 2012). These experimental, statistical and theoretical findings may be used to predict bagginess of fabrics based on their properties and prevent industrial about the most significant and influential inputs which they should be adjusted accurately. This work allows industrial, also, to make more attention, to ensure a high quality level, to optimize and review yarn behaviors used to produce fabrics against drastic solicitations and minimize frictions between yarn-to-yarns, metal-to-yarns (during experimental spinning and weaving processes) and further metal to-fabrics friction (during frequent consumer's uses).

3.2. Effect of fabric friction coefficient, MIU, on the residual bagging behavior

Figure 4 shows the linear regressions obtained to determine a relationship between the friction coefficient of fabric (MIU) and the residual bagging height R_{bh}, residual bagging volume, R_{bv} and bagging recovery, B_{rec}. According to Figure 4, acceptable regressions are carried out regarding the coefficients of regression values which are ranged from 74.7% to 86.4%. The effect of the MIU on the residual bagging height, the bagging recovery and the residual bagging volume is high and helps to understand the good relationship between the MIU coefficient and the residual bagging properties. Indeed, these important correlations can explain that the surface friction of the conformator participates widely on the bagging behavior of fabric samples. Besides, it may be concluded that the MIU value increase decreases both residual bagging height (Figure 5b) and volume (Figure 5c). However, when the MIU increases, the application of conformator on the surface of fabric is higher and helps to increase the bagging recovery. This result is in good agreement with the Zhang's study results (Zhang et al., 1997). As a consequence, frictional input parameter, MIU, remained as having high influence on the residual bagging behavior of denim fabrics and affects accurately the fabric appearance and shape. Basing on the high values of coefficient of regression it may be possible to predict residual bagging properties in studied experimental design of interest.

3.3. Effect of weft yarn density on the residual bagging behavior

Figures 6a, 6b, 6c and 4d show the effect of weft yarn density (Wt_D) of tested denim fabrics on the bagging recovery; residual bagging height and the residual bagging volume, respectively. The weft yarn density, Wt_D is an input parameter which seems influent on the yarn friction resistance because, more the density of the fabric is higher, lower the yarns can slide. So, the increase of the weft yarn density encourages the increase of the yarn-to-yarn friction resistance and as a consequence, the rigidity value increases too.

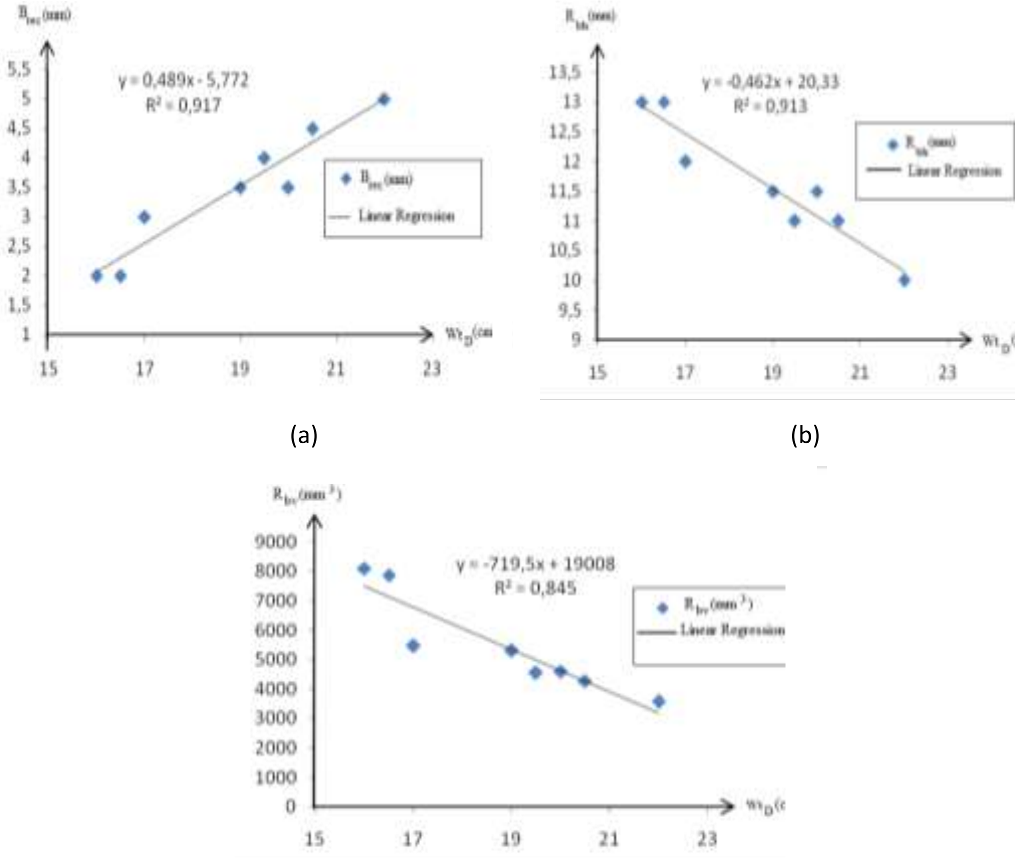


(a) (b)

(c)

Figure 5: Effect of the MIU on residual bagging behavior (a) as a function of B_{rec}; (b) as a function of R_{bh}; (c) as a function of R_{bv} values.

Otherwise, the results show that the weft yarn density have the same effects of the fabric friction coefficient, MIU, on the different bagging properties. Compared with the variation of MIU contributions on the bagging behavior, the weft yarn density effects presented higher coefficient of regressions. Indeed, they are ranged from 84.5% to 91.7% which contribute to predict the residual bagging behavior. In fact, the decrease of the residual bagging volume and height, when the weft density decreases, is explained by the yarn rigidity increase. This result is, also, proved by the Doustar's study results (Doustar et al., 2010). They have studied the effect of the weft density on bagging behavior of cotton woven fabrics and proved that there is a decrease of residual bagging hysteresis (expressed in percentage) when the weft density increases. For the evaluation of the contribution of the weft yarn density on the bagging recovery, Figure 6a, shows that there is a good relationship with a high coefficient of regression value (0.917). The increase of the weft yarn density encourages the bagging phenomenon to appear and consequently ameliorates the appearance of fabric. So, the input frictional parameters have positive effects to optimize the bagging recovery and minimize the shape of bagged zones in the garment.



(c)

Figure 6: Effect of the weft density on residual bagging behavior (a) as a function of B_{rec}; (b) as a function of R_{bh}; (c) as a function of R_{bv} values.

3.4. Principal Component Analysis (PCA) results

According to Figure 7, the PCA method results show the different correlations between inputs and outputs. Hence, four groups A, B, C and D are represented and describe the relationships obtained. The group A is composed by the weft rigidity (Wt_{rig}) and residual bagging volume (R_{bv}) which are correlated positively. The increase or decrease of the input generated the increase or the decrease of the whole appearance and the shape of the bagged zone. Indeed, the friction caused by yarns each other's changes widely the behavior of the residual volume. This finding seems important and can help to understand the variation of the shape of denim fabric bagging. Moreover, this result is in good agreement with those found using the linear regression method which proves that yarn-to-yarn friction is a significant parameter causing an aesthetic garment in the bagged zones. According to our results and in order to decrease the undesirable zones, it is suitable to maximize rigidity property of weft yarns, which can minimize widely the frictional forces between these yarns.

Therefore, group B is composed by one output only, the residual bagging height R_{bh} and three inputs such as the fabric rigidity (rig), the weight (M) and the breaking strength of the fabric (B_{st}). Referring to this positive correlation, it may be concluded that all these inputs affect badly the residual bagging height. In fact, the variation of one of them (inputs) implicates the variation of the R_{bh}. Due to this positive correlation in the group B, and the same inputs evolution and effects to the R_{bh}, the number of the inputs can be reduced accurately to study more widely, in further works, the contribution of the selected input in larger experimental design of interest. However, concerning the group C, there is a good relationship between the bagging recovery, B_{rec} and the weft yarn density, Wt_D which show that the increase of the number of weft yarns per centimeter helps the bagging recovery. As a result, to reduce the bagging appearance it is suitable to use minimal weft yarns per centimeter. This finding confirmed the result obtained previously using the linear regression technique.

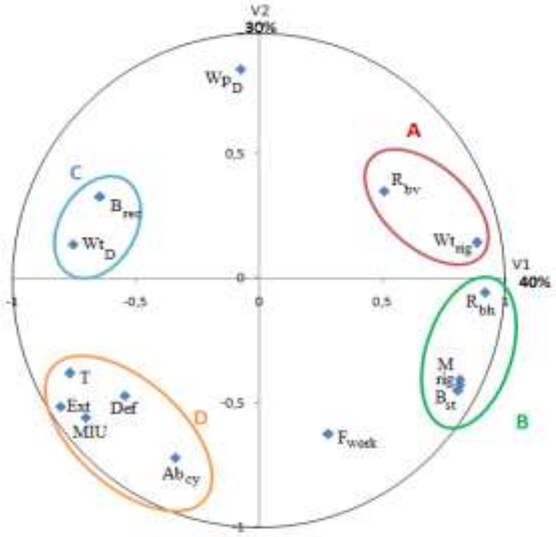


Figure 7: Processing of the results with principal component analysis (PCA)

In contrast with other groups, the group D is composed by all inputs only correlated positively such as the number of abrasion cycles (Ab_{cy}), the fabric coefficient of friction MIU, the weft breaking extension (Ext), the weft yarn breaking deformation (Def) and the weft yarn tenacity, T. So, basing on the PCA method, it is sufficient to study one input effect among the overall grouped parameters. Indeed, because the frictional parameter, MIU is the most interesting input in this work, we selected it as the remained parameter. Besides, it is remarkable regarding this group that the number of abrasion cycles applied to weft yarns is in good agreement with the MIU parameter, which proves that there is a good relationship between these inputs. The friction between yarns increases when the number of abrasion cycles increases. This result was found by Jaouachi et al. (Jaouachi et al., 2012).

Knowing the relationships between all inputs and outputs in the groups mentioned above, there are some interactions between groups. Figure 5 shows that group A and group B are correlated positively as well as group C and D according to V1-axis. The increase/decrease of one input or output of group A, for example, increases/decreases the input or output of group B and vice versa. This same conclusion can be extrapolated to the other groups, C and D according to the V1-axis. However, the results show also that there are four negative correlations which can be considered between all groups. For example, group A and C are correlated negatively which means that the decrease of one input of group A increases the output of group C. Basing on the comparative findings obtained using the two methods, linear regression and PCA techniques, it may result that there is a good agreement between the tested frictional inputs and the residual bagging behavior of studied fabrics. Hence, it can be explained that the yarn-to-yarn friction and the friction caused by the contact of conformator to the fabric surface remained function of some influential inputs and their relationships with the bagging behavior which are highly significant.

4. CONCLUSION

In this study, the bagging behavior as function of frictional fabric and yarn parameters relative to different denim fabrics was investigated using two different methods, linear regression and Principal Component

Analysis, PCA. To analyze objectively the effects of frictional input parameters on the residual bagging behavior, eight denim fabrics with their principal characteristics were investigated and compared. Interesting relationships between frictional inputs such as yarn-to-yarn friction, expressed by both weft yarn rigidity and the number of abrasion cycles applied, fabric frictional parameter, MIU, and the residual bagging behavior (residual bagging height, residual bagging volume and bagging recovery properties) are established. The coefficient of regression values are ranged from 74.7% to 91.7% which explain the possibility of bagging behavior prediction in the studied experimental field of interest. Referring to the results, it may be concluded that the frictional parameters affected widely the residual bagging behavior. Indeed, the increase of the weft yarn density and the fabric friction coefficient decrease the residual bagging height and residual bagging volume. In contrast, they increase the bagging recovery of all studied denim fabric samples.
Otherwise, the results show that there is good and positive correlations between the weft yarn rigidity and the bagging behavior. To prove accurately our results, the PCA analysis was applied and showed, also that good correlations between the tested frictional inputs and the bagging outputs are acceptable and significant. Further works follow.

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