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# Influence of Weave Type and Weft Density on Worsted Fabric Pilling

**Abstract**
*Pilling in textiles has been one of the most significant areas which many researchers, such as Cook, have investigated. In this study, we analysed the pilling of several samples of worsted fabrics: 45% wool/55% polyester with different weft densities and weave types. Rubbing test results were obtained using the Martindale test and by counting pills on the fabric surface assumed. The results show that the more the warp and weft are engaged together in the fabric surface, the fewer pills will form on it; or one may conclude that, in some cases, less pilling forms on the surface when the warp outnumbers the weft (i.e. less engagement between warp and weft), provided that the density of the warp is far larger than that of the weft. But in some fabrics, increasing the weft density will form fewer pills on the surface fabric.*

**Key words:** *worsted fabrics, weave type, weft density, pilling.*

## Introduction

Pilling is an important problem not only for textile and clothes manufacturers but also for users. The effect of the pilling process results in a significant decrease in fabric quality and a negative influence on user comfort [1].

Sirospun yarns are quite sufficient and comparable to two-plied yarns in many of the performance characteristics of woven worsted fabrics when optimum conditions are provided in their production process. Such fabrics resist the formation of pilling and abrasion at nearly the same level, and have a similar appearance [2].

Apart from the high variety of garment designs, durability is also an important factor. Therefore certain specifications like pilling, which affects durability, is one of the critical problems in the garment industry.

Pilling is a fabric defect which is observed as small fibre balls or groups consisting of intervened fibres that have been attached to the fabric surface by one or more fibres [3].

Pilling often represents a serious defect in a fabric or garment. Not only does it detract from the appearance and handle of the product, but it also has an accelerating effect on the rate of fibre removal from the yarn structure, hence materially reducing the service life [4].

Through the pill formation process, fibre entanglement makes some deformities on the fabric surface [5].

Pill initiation and development follow a well-established pattern with six stages:

1. The establishment of a localised area of high fuzz density,
2. The development of a loose entanglement within that area,
3. The tightening of the entanglement into a roughly spherical mass of fibre,
4. The pulling out of the anchor fibres to form a discrete, mobile pill,
5. The fracture of certain fibre due to the relocation of a pill,
6. The fracture of remaining fibre and the loss of the pill [6].

Micro-pill development is covered by the first three steps, which means the first entanglement zone.
The development of fuzz into a pill is shown in ***Figure 1***.

Gintis and Mead showed that the increased strength and flex life of synthetic fibres reduces the rate of pill wear-off, resulting in higher pill densities and a greatly increased pill life. In addition, the tenacity and rigidity of the fibres affect the fuzz-development phase 2 - 6 and subsequent fuzz entanglement in such a way that fibres with a relatively high te-

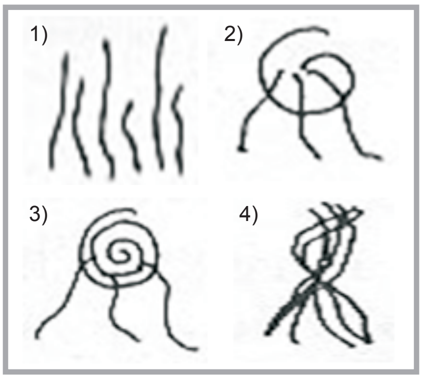


***Figure 1.*** *Steps in pill formation [5]; 1) fuzz, 2) loose entanglement, 3) pill (tight entanglement), 4) spiral entanglement.*



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nacity and low bending rigidity generate high fuzz densities with high rates of initial pill development [4].

Brand and Bohmfolk assume in their model of pilling that fuzz fibres disappear from the fabric surface through abrasion or pull-out, while Motoji and Tsujimoto consider fibre deformation beyond the yield point to be partly responsible for initial entanglement but do not provide any clear evidence of fibre damage remote from the pill site [4].

Pilling is generated by repeated friction forces acting according to two combined phenomena: the emerging of fibres from the fabric surface and the persistence of neps formed on the same surface. The first phenomenon increases with low bending modulus fibres and a low friction coefficient, while the second one increases when fibres have a high tensile strength and high bending recovery. It is generally understood that pilling is particularly high in the case of fabrics containing synthetic fibres, such as polyamide and polyester [3].

In cases where the fibre tensile forces are insufficient to overcome frictional forces within the yarn, pill growth is restricted, and the roll-up process leads to pill immobilisation (***Figure 2***) and an increased pill life due to the reduced scale of cyclic bending and torsional strain in the fibres [6].

High twist factors and tight fabric structures lead to low pull-out and restricted pill growth and, for fibres with high tensile strengths, the pills that form are likely to become immobile and remain on the fabric surface without wearing off. The

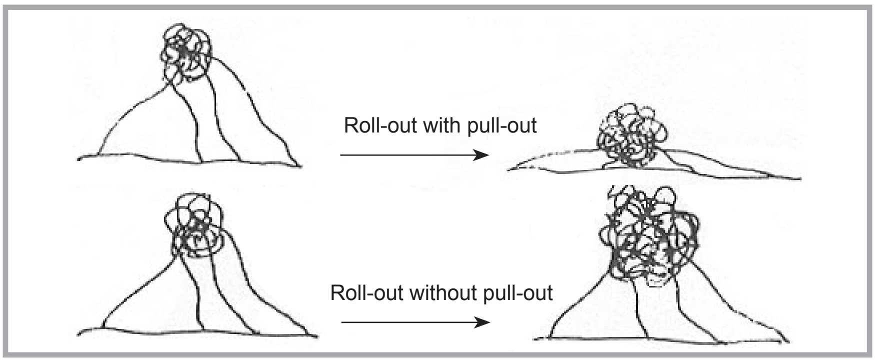


***Figure 2.*** *Pilling processes [6].*

***Table 1.*** *Sample technical data.*

| Sample no. | Warp and weft count, tex | Weave type | Weft density, weft/cm | | | | | Warp density, warp/cm |
|---|---|---|---|---|---|---|---|---|
| 1 | 50/2 | Twill 1/2 Left to Right | 15 | 16 | 17.25 | 18.5 | | 26 |
| 2 | 50/2 | Twill 2/1 Left to Right | 15 | 16 | 17.25 | 18.5 | | 26 |
| 3 | 38.4/2 | Twill 2/1 Left to Right + Twill 1/2 Left to Right | 21 | 22 | 23 | 24 | | 26.25 |
| 4 | 38.4/2 | Twill 2/2 Left to Right | 21 | 22 | 23 | 24 | | 27 |
| 5 | 25/2 | Satin 4/1↑2 | 28 | 29 | 30 | 31 | | 40 |
| 6 | 25/2 | Twill 1/2 Right to Left + Twill 2/1 Left to Right | 25 | 26 | 27 | 28 | 29 | 31.5 |

mean length of fibres extracted from the fabric surface affects pill size [6].

Improved resistance to abrasion due to increased fabric sett is understandable because as the sett increases (***Figure 3***), the fabric becomes more compact and fibre-to-fibre and yarn-to-yarn friction increases [7].

Computed changes in fabric properties due to changes in the weave structure are shown in ***Figure 4***. In terms of resistance to abrasion, plain weave is the best, and 2/1 twill is better than 2/2, 3/1, or 4/1 twill. Plain weave fabrics have the highest shear rigidity compared with other weaves. These trends are in agreement with the common knowledge that there is more yarn-to-yarn interlacing in fabrics with smaller weave floats [7].

The pilling of worsted fabrics is a serious problem and has attracted the attention of customers, manufacturers and researchers. In this work, the effect of fabric parameters including the weave type and weft density on the pilling of worsted fabrics was investigated using the statistical analysis method.

## Experimental

In this study, we used worsted 45% Wool/55% Polyester fabrics with different warp and weft yarn counts,

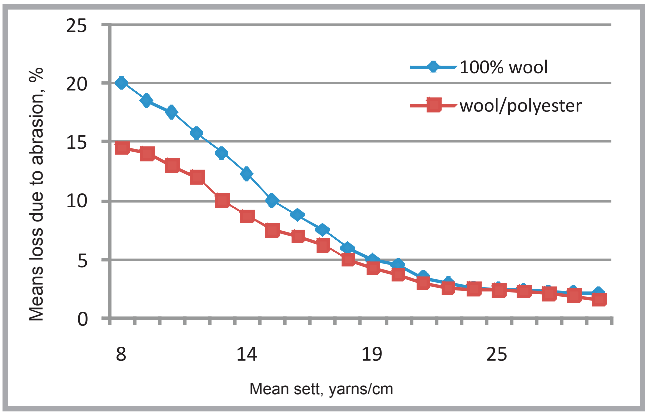


***Figure 3.*** *Effect of sett on fabric, assuming a constant yarn linear density of 50 tex, a constant weave crimp of 8%, a changing fabric sett from 29×27 to 10×8, and plain weave fabric [7].*

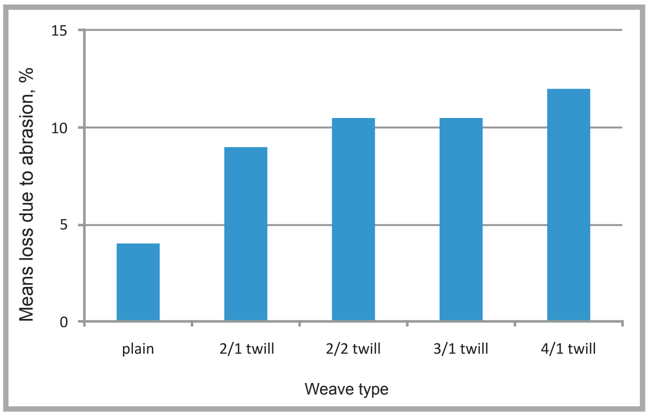


***Figure 4.*** *Effect of weave structure on fabric properties, assuming the warp and weft yarn linear density are 50 tex, sett 21×19, composition 22 μm wool, twist 590Z/540S [7].*

***Table 2.*** *Technical data for wool fibre of 50/2 tex yarn count.*

| Test type | Test result |
|---|---|
| Fibre fineness, μm | 23.3 |
| Weight of sliver, g/m | 18.67 |
| Mean length, mm | 57 |

***Table 3.*** *Technical data for polyester tops of 50/2(tex) yarn count.*

| Test type | Test result |
|---|---|
| Fibre fineness, dtex | 3 |
| Mean length, mm | 66.6 |

weave types and weft densities, supplied by the Iran Merinos and Motahhari Companies. Detailed specifications of the samples are listed in ***Table 1***. It must be noted that the fibre processes and spinning systems are exactly the same.

Each sample was processed with 4 different weft densities, apart from sample no. 6, which had five different weft densities. The size of the samples was 90 × 150 cm. We prepared 3 pieces of each sample, the back and front, and the warp and weft directions were marked.

To ensure the randomness of the tests, we chose samples from different places of the fabric surface. It must be noted that in the Martindale test, two pieces of the samples must be in full contact with each other.

Tests were performed in standard conditions (65% RH and 20 °C). In the pilling test, one piece of the sample had to be set on the lower head of the machine i.e. on the felt, and the smaller piece had to be adjusted to the moving head of the machine.

The test cycles were set at 125, 500, 750, 1000, 1500 and 2000 according to ISO 12945-2000. After each test run, the number of pills was counted horizontally by a magnifier under a fluorescent light. It must be noted that the light should be set at an angle of 5 to 15 degrees to the fabric surface, and also the distance between the samples and the eye must be between 30 to 50 cm. The mean value of the number of pills of each sample was recorded [8].

**Raw Material Specifications**

The specifications of wool fibres processed to a 50/2 (tex) yarn count by the Iran Merinos company are listed in ***Table 2***. Technical data of the polyester fibre are also given in ***Table 3***.

Technical data of fibre processed to a 38.4/2 tex and 25/2 tex yarn count by the Motahhari company can also be seen in ***Tables 4, 5*** and ***6***.

## Results and discussion

The yarn twist quantity could affect the pilling properties of fabrics. An increase in the twist factor results in a decrease in fibre migration, fuzz generation and pilling. We used the same t.p.m. and twist direction for the weft and warp yarn samples to eliminate the effect of the twist parameter on the pilling fabrics.

***Table 4.*** *Technical data for wool fibre of a 38.4/2 tex and 25/2 tex yarn count.*

| Test type | Test result | |
|---|---|---|
| | 38.4/2 tex | 25/2 tex |
| Fibre fineness, μm | 22 | 19 |
| Weight of sliver, g/m | - | 20.64 |
| Mean length, mm | 70 | 63 |

***Table 5.*** *Technical data for polyester tops of a 38.4/2 tex and 25/2 tex yarn count.*

| Test type | Test result | |
|---|---|---|
| | 38.4/2 tex | 25/2 tex |
| Fibre fineness, μm | 2.4 | 2.4 |
| Mean length, mm | 91 | 91 |

***Table 6.*** *Technical data for yarn twist and Twist direction.*

| Warp and weft count, tex | t.p.m (two-ply) | twist direction (two-ply) | t.p.m (one- ply) | twist direction (two-ply) |
|---|---|---|---|---|
| 50/2 | 575 | S | 662 | Z |
| 38.4/2 | 636 | S | 732 | Z |
| 25/2 | 821 | S | 944 | Z |

**Worsted fabric with 50/2 tex warp and weft**

As regards sample 1, (weave: twill 1/2 Left to Right) from ***Figure 5.a*** it is obvious that when the weft density is increased first from 15 to 16 and then to 18.5, the number of pills decreases from 69 to 60. This approach is continued by increasing the weft density.

Moreover, ***Figure 5.b*** illustrates that by increasing the weft density of the fabric (x), the number of pills (y) decrease according to the linear equation $y = 108.415 – 2.641x$ and correlation coefficient - 0.699.

According to ***Table 7***, the significance level of the examination is less than 5%, and it is concluded that there is a real relation between pilling and the weft density of fabric.

As regards sample 2 (weave: Twill 2/1 Left to Right), in ***Figure 6.a*** we can see that the number of pills decreases from 65 to 51 when the weft density is increased first from 15 to 16 and then to 18.5.

Moreover, in ***Figure 6.b*** it is illustrated that by increasing the weft density of the fabric (x), the number of pills (y) decreases according to the linear equation $y = 123.245 – 3.805x$ and correlation coefficient - 0.758.

According to ***Table 8***, the significance level of the examination is less than 5%, and it is concluded that there is a real relation between pilling and the weft density of fabric.

The computed sig from the T test in ***Table 9*** is about 0.05, which means samples 1 and 2 are obviously different in their responses to the test. The mean value of pills in sample 2 is lower compared to sample 1.

Samples 1 and 2 have nearly the same weave construction as well as the same twist per meter and twist direction: sample 1 - twill 1/2 left to right and sample 2 - twill 2/1 left to right). However, there is more warp yarn on the fabric surface in sample 2, and the density of the warp is far more than that of the weft, hence fibres cannot easily come out from the fabric surface to form pills, and thus the number of pills is fewer than in sample 2.

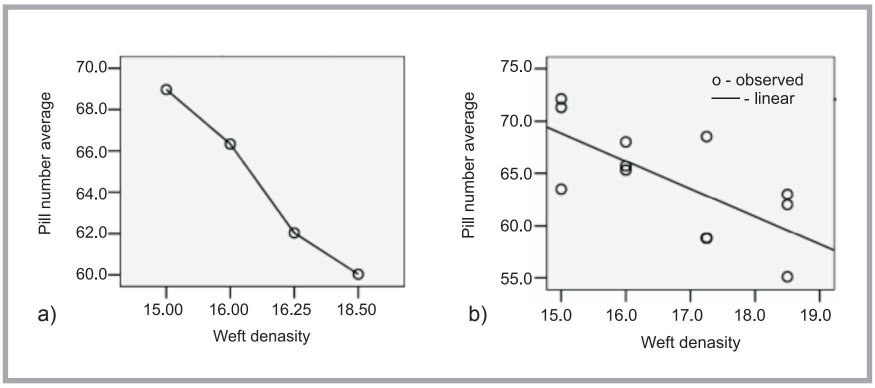


*Figure 5. Effect of weft density on pill formation (a) and curve estimation of regression (b) for sample 1 - Twill 1/2 Left to Right.*

*Table 7. Analysis of regression and parameter estimates for sample 1 - Twill 1/2 Left to Right; Dependent variable: average number of pills, independent variable: weft density.*

| Equation | Model summary | | | | | Parameter estimates | |
|---|---|---|---|---|---|---|---|
| | R. square | F | df1 | df2 | Sig. | constant | b1 |
| Linear | 0.488 | 9.528 | 1 | 10 | 0.012 | 108.415 | -2.641 |

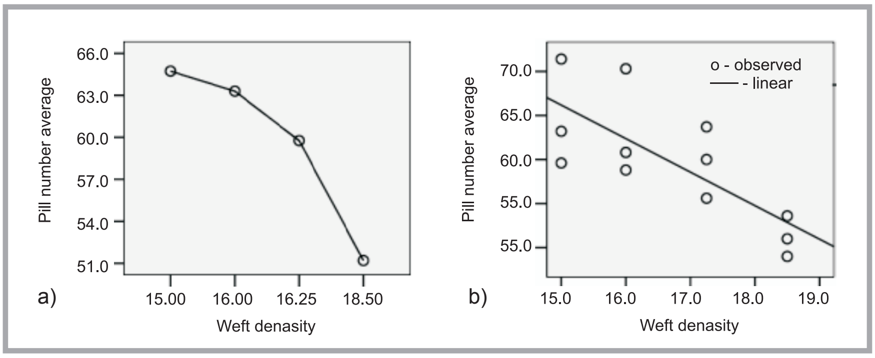


*Figure 6. Effect of weft density on pill formation (a) and curve estimation of regression (b) for sample 2 - Twill 2/1 Left to Right.*

*Table 8. Analysis of regression and parameter estimates for sample 2 - Twill 2/1 Left to Right; Dependent variable: average number of pills, independent variable: weft density.*

| Equation | Model summary | | | | | Parameter estimates | |
|---|---|---|---|---|---|---|---|
| | R. square | F | df1 | df2 | Sig. | constant | b1 |
| Linear | 0.574 | 13.473 | 1 | 10 | 0.004 | 123.245 | -3.805 |

*Table 9. T test for sample 1 (Twill 1/2 Left to Right) and sample 2 (Twill 2/1 Left to Right).*

| Group statistics | | | | | |
|---|---|---|---|---|---|
| | (Twill 1/2 Left to Right) = 0 & (Twill 2/1 Left to Right) = 1 | N | Mean | Std. deviation | Std. error mean |
| Pills (Twill 1/2 Left to Right) | 0.00 | 12 | 64.3417 | 5.19501 | 1.49967 |
| (Twill 2/1 Left to Right) | 1.00 | 12 | 59.7500 | 6.90053 | 1.99201 |

| Independent Samples Test | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Equal variance | Levene's test for equality of variance | | t-test for equality of means | | | | | | |
| | | F | Sig. | t | df | Sig. (2-tailed) | mean difference | std. error difference | 95% confidence interval of the difference: lower | upper |
| Pills (Twill 1/2 Left to Right) & (Twill 2/1 Left to Right) | assumed | 0.453 | 0.508 | 1.842 | 22.0 | 0.079 | 4.5917 | 2.4934 | -0.5794 | 9.7627 |
| | not assumed | | | | 20.4 | 0.080 | | | -0.6024 | 9.7857 |

It is obvious from ***Figures 5.a*** and ***6.a*** that whenever the weft density is increased, fibres cannot be free from the yarn structure and appear on the fabric surface to form pills. On the other hand, increasing the weft density results in fewer pills on the fabric surface.

**Worsted fabric with 38.4/2 tex warp and weft**

In sample 3 (Twill 2/1 Left to Right + Twill 1/2 Left to Right) and sample 4 (Twill 2/2 Left to Right), we had different responses. To be certain of the result, the test was done again, with the same outcome. As can be seen in ***Figures 7.a*** and ***8.a***, (see page 68) the results are changed in a different way.

In sample 3, according to ***Figure 7.b***, (see page 68) by increasing the weft density of fabric (x), the number of pills (y) are increased according to the linear equation y = 2.133 + 0.633x and correlation coefficient - 0.212. However, the significance level of the examination is more than 5% in ***Table 10*** (see page 68). It is concluded that the number pills are not dependent on the weft density of fabric.

In sample 4, according to ***Figure 8.b***, (see page 68) by increasing the weft density of the fabric (x), the number of pills (y) decrease according to the linear equation y = 41.033 - 1.003x and correlation coefficient - 0.241. Although the significance level of the examination is more than 5% in ***Table 11*** (see page 68), it can be concluded that the number of pills is not dependent on the weft density of fabric.

The computed sig from the T test in ***Table 12*** (see page 68) is more than 0.05, hence there is no obvious difference between the test results for samples 3 and 4, According to the mean values, the number of pills in sample 3 is lower.

The factors of warp and weft densities are not significant for this sample because the density of the warp is lower than that of the weft in samples 3 and 4. However, in the weaves Twill 2/1 Left to Right + Twill 1/2 Left to Right and Twill 2/2 Left to Right, more warp and weft are interlaced together on the fabric surface because fibres cannot easily come out from the fabric surface with weave Twill 2/1 Left to Right + Twill 1/2 Left to Right to form pills. Therefore, there are fewer pills in sample 3.

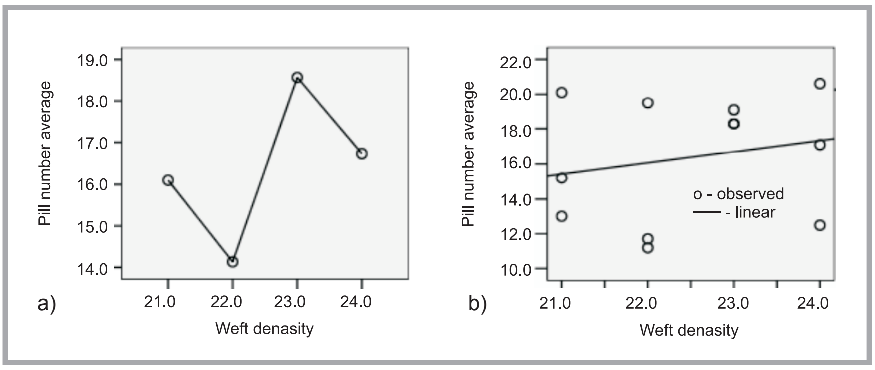


***Figure 7.*** *Effect of weft density on pill formation (a) and curve estimation of regression (b) for sample 3 - Twill 2/1 Left to Right + Twill 1/2 Left to Right.*

***Table 10.*** *Analysis of regression and parameter estimates for sample 3 - Twill 2/1 Left to Right + Twill 1/2 Left to Right; Dependent variable: average number of pills, independent variable: weft density.*

| Equation | Model summary | | | | | Parameter estimates | |
|---|---|---|---|---|---|---|---|
| | R. square | F | df1 | df2 | Sig. | constant | b1 |
| Linear | 0.045 | 0.473 | 1 | 10 | 0.507 | 2.133 | 0.633 |

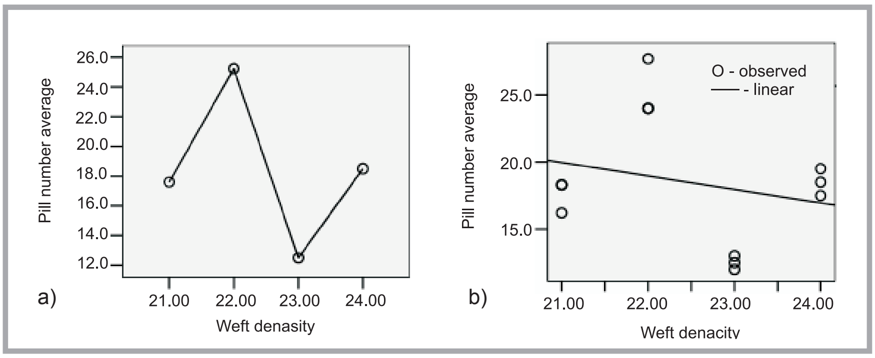


***Figure 8**. Effect of weft density on pill formation (a) and curve estimation of regression (b) for sample 4 - Twill 2/2 Left to Right.*

***Table 11.*** *Analysis of regression and parameter estimates for sample 2 - Twill 2/1 Left to Right; Dependent variable: average number of pills, independent variable: weft density.*

| Equation | Model summary | | | | | Parameter estimates | |
|---|---|---|---|---|---|---|---|
| | R. square | F | df1 | df2 | Sig. | constant | b1 |
| Linear | 0.058 | 0.614 | 1 | 10 | 0.451 | 41.033 | -1.003 |

***Table 12.*** *T test for sample 3 (Twill 2/1 Left to Right + Twill 1/2 Left to Right) and sample 4 (Twill 2/2 Left to Right).*

| Group statistics | | | | |
|---|---|---|---|---|
| (Twill 2/1 Left to Right + Twill 1/2 Left to Right) = 0 & (Twill 2/2 Left to Right) = 1 | N | Mean | Std. deviation | Std. error mean |
| Pills (Twill 2/1 Left to Right + Twill 1/2 Left to Right) 0.00 | 12 | 16.3833 | 3.4808 | 1.0048 |
| (Twill 2/2 Left to Right) 1.00 | 12 | 18.4583 | 4.8710 | 1.4061 |

| Independent Samples Test | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Equal variance | Levene's test for equality of variance | | t-test for equality of means | | | | | | |
| | | | | t | df | Sig. (2-tailed) | mean difference | std. error difference | 95% confidence interval of the difference | |
| | | F | Sig. | | | | | | lower | upper |
| Pills (Twill 2/1 Left to Right + Twill 1/2 Left to Right) & (Twill 2/2 Left to Right) | assumed | 0.270 | 0.608 | -1.201 | 22.0 | 0.243 | -2.0750 | 1.7282 | -5.659 | 1.5092 |
| | not assumed | | | | 19.9 | 0.244 | | | -5.681 | 1.5311 |

As mentioned before, ***Figures 7.a*** and ***8.a*** have different graphs, presenting the relation between weft density and pilling.

**Worsted fabric with 25/2 tex warp and weft**

As regards sample 5, weave Satin 4/1↑2, it can be seen in figure 13 that the number of pills decreases from 47 to 33 when the weft density is increased first from 28 to 29 and then to 31.

For sample 5, according to ***Figure 9.b***, by increasing the weft density of the fabric (x), the number of pills (y) decreases according to equation linear $y = 162.573 – 4.22x$ and correlation coefficient - 0.806.

According to ***Table 13***, the significance level of the examination is less than 5%, and it is concluded that there is a real relation between pilling and the weft density of fabric.

For sample 6, with weave: Twill 1/2 Right to Left+ Twill 2/1 Left to Right, the number of pills decreases with an increase in weft density, and then there is an increase in the number of pills, which is contrary to our theory. To be certain of the result, the last test was done again, and the outcome was the same. It is possible that the direction of S and Z in the weave construction can have an influence on the results.

As regards sample 6, according to ***Figure 10.b***, by increasing the weft density of the fabric (x), the number of pills (y) increases according to the linear equation $y = -32.517 + 3.957x$ and correlation coefficient - 0.531.

According to ***Table 14***, the significance level of the examination is less than 5%, and it is concluded that there is a real relation between pilling and the weft density of fabric.

In ***Table 15***, the computed sig from the T test is less than 0.05, hence the difference between the results for samples 5 and 6, with respect to the increase in weft density, is obviously remarkable.

Because the warp and weft in sample 6 is interlaced more than in sample 5, there must be fewer pills on the surface of sample 6; however, the density of the warp is far more than that of the weft in sample 5, hence fibres cannot easily come out from the fabric surface to form pills.

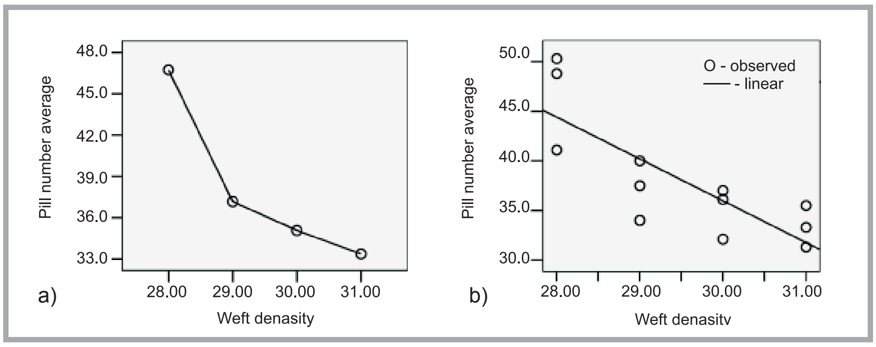


*Figure 9. Effect of weft density on pill formation (a) and curve estimation of regression (b) for sample 5 - Satin 4/1↑2.*

***Table 13.*** *Analysis of regression and parameter estimates for sample 5 - Satin 4/1↑2 to Right; Dependent variable: average number of pills, independent variable: weft density.*

| Equation | Model summary | | | | | Parameter estimates | |
|---|---|---|---|---|---|---|---|
| | R. square | F | df1 | df2 | Sig. | constant | b1 |
| Linear | 0.651 | 18.650 | 1 | 10 | 0.002 | 162.573 | -4.220 |

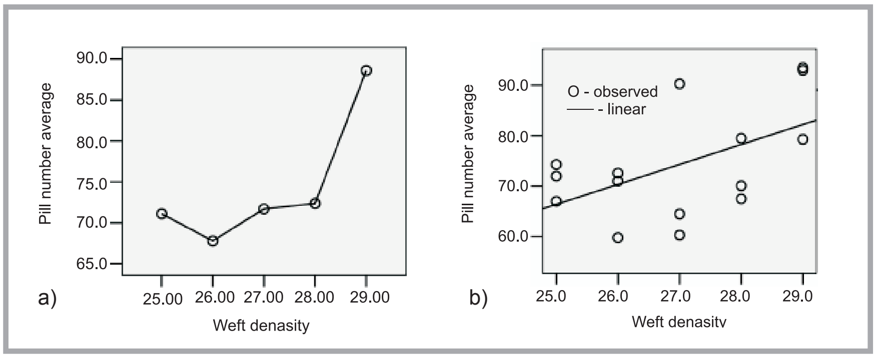


*Figure 10. Effect of weft density on pill formation (a) and curve estimation of regression (b) for sample 6 - Twill 1/2 Right to Left + Twill 2/1 Left to Right.*

***Table 14.*** *Analysis of regression and parameter estimates for sample 6 - Twill 1/2 Right to Left + Twill 2/1 Left to Right; Dependent variable: average number of pills, independent variable: weft density.*

| Equation | Model summary | | | | | Parameter estimates | |
|---|---|---|---|---|---|---|---|
| | R. square | F | df1 | df2 | Sig. | constant | b1 |
| Linear | 0.282 | 5.108 | 1 | 13 | 0.042 | -32.517 | 3.957 |

***Table 15.*** *T test for sample 5 (Satin 4/1↑2) and sample 6 (Twill 1/2 Right to Left + Twill 2/1 Left to Right).*

| Group statistics | | | | | |
|---|---|---|---|---|---|
| (Satin 4/1↑2) = 0 & (Twill 2/1 Left to Right) = 1 | | N | Mean | Std. deviation | Std. error mean |
| Pills (Satin 4/1↑2) | 0.00 | 12 | 38.0833 | 6.1078 | 1.7632 |
| (Twill 1/2 Right to Left + Twill 2/1 Left to Right) | 1.00 | 12 | 75.1167 | 12.0541 | 1.4797 |

| Independent Samples Test | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Equal variance | Levene's test for equality of variance | | t-test for equality of means | | | | | 95% confidence interval of the difference | |
| | | F | Sig. | t | df | Sig. (2-tailed) | mean difference | std. error difference | lower | upper |
| Pills (Satin 4/1↑2) & (Twill 1/2 Right to Left + Twill 2/1 Left to Right) | assumed | 6.901 | 0.015 | -9.493 | 22.0 | 0.000 | -37.033 | 3.9009 | -45.12 | -28.94 |
| | not assumed | | | | 16.30 | | | | -45.29 | -28.78 |

Furthermore the density of the warp is less than that of the weft in sample 6, therefore fibres can easily come out from the fabric surface to form pills, hence we have fewer pills in sample 5 compared to sample 6.

***Figure 9.a*** shows that whenever the weft density is increased, fibres cannot easily come out from the fabric surface to form pills. On the other hand, increasing the weft density results in fewer pills on the fabric surface. But in ***Figure 10.a*** we have different results.

## Conclusion

1. The density of warp and weft yarns affects the pilling of worsted fabrics.
2. The weave type and interlacing warp yarn with weft yarn also influence the pilling of worsted fabrics. However, when the density of the warp is far more than that of the weft, warp density has more of an effect than the weave type on the pilling of worsted fabrics.
3. In weaves, whenever the more warp and weft are interlaced together in the fabric surface, the change in the number of pills is less with increasing weft density.
4. The statistical investigations presented herein, based on regression equations and graphs, illustrate that the number of pills decreases in more samples (1, 2, 4 and 5) when the weft density is increased.

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