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Engineering of Tearing Strength for Pile Fabrics

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ABSTRACT

The tearing strength has a great correlation with the fabric serviceability, since the threads are broken singly during the test, which is the common mode of the fabric failure during usage. The aim of this work is to study some factors affecting the tearing strength of pile fabrics.

Nine factors were studied concerning machine settings, fabric structure, yarn type, and yarn count. Fractional Factorial Experiments on production scale were applied. Two groups were obtained and tested; before and after back sizing, each of them had 32 samples. Tearing strength was measured using the Trapezoidal method.

Significant Regression Relations were obtained concerning these factors and the fabric tearing strength. Based on the statistical analysis, significant factors were identified. The tearing strength is affected to a great extent by type and count of weft yarns, weft density, ground structure, and tension on ground yarns, while pile shape and pile designation shifting have lesser effects.

Keywords: Tearing strength, Pile, Three positions, Face-to-Face, Regressions

1. Introduction

Tearing strength is an indicator of the useful life for clothing, furniture, and military fabrics (8). The importance of tearing strength springs from the fact that it is more closely related to serviceability than tensile strength (4). Therefore, it could be considered an assessment of serviceability (9). Tearing strength has certain features: a) the cloth fails by the breaking of the thread one at a time, or at least in very small groups. b)Distortion due to the skewing of the threads, c) the occurrence of slippage of one set of threads over the other (7).

Tearing occurs when stresses imposed on a fabric result in a concentration of stress at a point, leading individual yarns to failure (1). Only one or at most a few yarns share the load (4). The tear propagates when failure of one yarn results in the load being transferred to the adjacent yarn which then fails in turn. Frictional constraints at yarn interlacing and yarns extensibilities control the resistance of tearing(1).So, tearing strength is shown to be dependent mainly on the spacing and strength of the threads being torn, and the force required to make them slip over the crossing threads(7). The interactive relationship between yarn tensile properties and yarn mobility is obviously at the base of fabric tear performance (2). Greater extensibility or reduced frictional constraints allow the yarns to bunch at the tear; and therefore increase the tearing strength. Although the yarn strength is secondary to extensibility, *rip-stop* yarns of greater strength are effective in increasing tear strength (1), however Mukhopadhyay and their colleagues noticed that higher yarn strength may not necessarily lead to higher tear strength (6).

Loose, open constructions allow more freedom for the yarns to move and group together, thus presenting bundles of yarns to the tearing load, consequently the tearing strength becomes high (4). Designs which have groups of yarns woven together, such as rib weaves and basket weaves, will have high tear strength, while plain weave should be weaker in tear than the basket weave (8). Finishing, easy care treatments and coating tend to reduce the tearing strength of woven fabrics, especially if they restrict the freedom of movement of the yarns under loading (4). Therefore, it can be stated that with the change in process variation, fabric tear strength is much more susceptible to change than breaking strength (6).

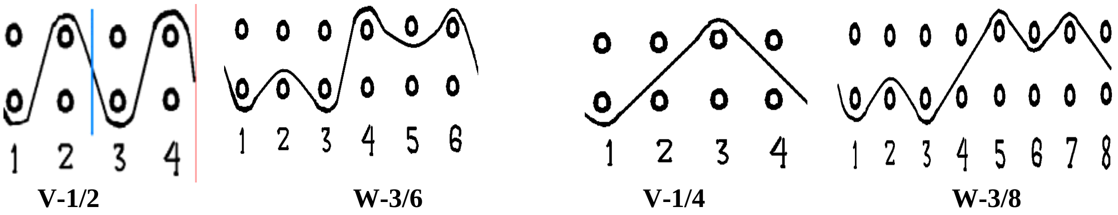
1.1 Pile fabric constructions

For pile fabrics, two warp systems at least are used; one for forming the supporting ground with the wefts, the other one for forming the pile layer (5). Pile warp threads are generally double or triple to form *fuzzy* surface after cutting that better cover the ground weave (3).

The most famous shapes for the pile tufts are **V**-shaped, where each pile is anchored by one base filling, and **W** – shaped, where each pile is anchored by three base fillings at least. **V**-shaped is written as V-1/2. This means that the pile loop extends over one filling, and the loop forming path is repeated after two fillings. **W**-shaped is written as W-3/6. This means that the pile loop extends over three fillings, and the loop forming path is repeated after six fillings, as shown in figure (1-a). By shifting the pile designation, **V**-shaped and **W**-shaped could be V-1/4 and W-3/8. This means that the pile loops extend over one &three fillings, but the loop forming path is repeated after four& eight fillings successively (5), as shown in figure (1-b). So, there will be less pile density on the surface of the fabric by shifting the pile designation. Tension ratios of the part ground warp yarn systems play a very decisive role.

Different tension levels on the two parts of the ground warp yarns, for the same fabric, gives better facility to insert picks, less shrinkage on the fabrics in width (5).

There will be also two possibilities for pile yarns, to move either with the slack warp (through the back of the fabric), or with the tight warp (not through the back of the fabrics) (5), as shown in figure (2).Pile yarns can be working in groups. If they are two groups, each group can be put in two healds for moving separately, this movement is either in opposite position, when they are anchored with the same two picks at one cycle of the machine in the double shedding, or in delayed movement of one pile group anchored with the second pick at the second cycle of the machine. This makes different contribution for pile tufts on the surface of the fabric, as shown in figure (3).



(a) The basic shape of pile V&W (b) Shifting the designation of pile V&W

Fig. (1) V&W pile configurations

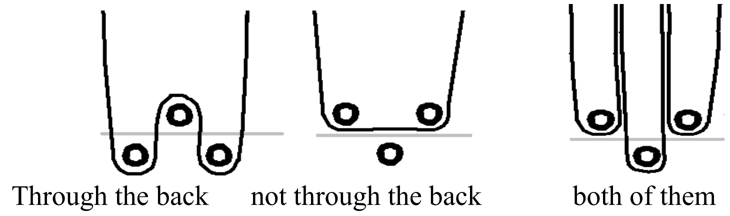


Fig. (2) Pile possibilities with different tension levels on warp ground yarns

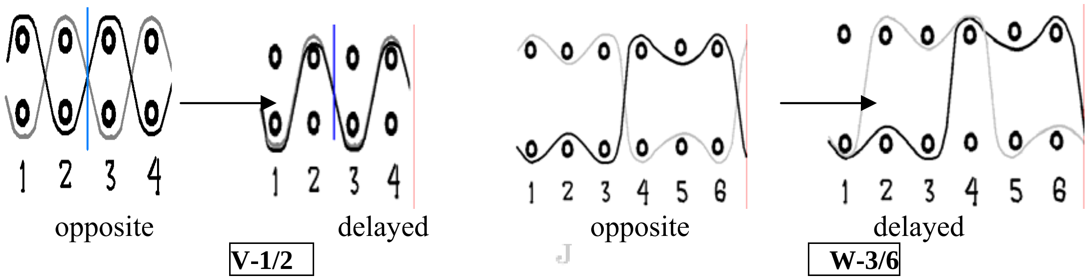


Fig. (3) The movement possibilities of two groups of warp pile yarns

2. Materials and methods

The experimental work was carried out on production scale. The weaving machine has the following conditions: Face-to-Face looms with Dobby device for shedding formation with three positions. Two warp beams& four healds were used for warp pile yarns (100% Acrylic, 16/2 Ne). Two warp beams& four healds were used for warp ground yarns (100% Polyester, 30/2 Ne).

Two levels (1/16) Fractional Factorial experiment was applied for nine factors with a total of $2^{\wedge\,(9-4)}$ =32 Experiments. The factors under considerations and their levels are shown in table (1). The specifications of the warp & weft yarns are shown in table (2).Two layers of fabrics were produced; one layer was tested after being obtained from the weaving machine while the other was tested after being treated with back sizing.

The Tearing strength for the 64 samples was determined in both directions of the fabrics. The test was produced on the tensile tester model X_3(Scott tester Inc.). The speed of the pulling clamp was 12 inches per minute, with a capacity of 0-75 pounds. The strength was evaluated by the trapezoidal method in the warp and weft directions.

Table (1) Factors under study and their levels

Serial No.	code	parameter	Level 1 (-)	Level 2 (+)
1	**X_1**	**The type of weft yarns**	**Polyester**	**cotton**
2	**X_2**	**Weft yarn count (Ne)**	**20/2**	**30/2**
3	**X_3**	**No. of picks/cm**	**16**	**18**
4	**X_4**	**Tension levels on warp ground yarns**	**Equal**	**Different**
5	**X_5**	**Ground structure**	**Plain**	**Warprib2/2**
6	**X_6**	**Pile shape of pile beam yarns No.1**	**V**	**W**
7	**X_7**	**Pile shape of pile beam yarns No.2**	**V**	**W**
8	**X_8**	**Shifting the pile designation**	**V-1/2**	**V-1/4**
			W-3/6	**W-3/8**
9	**X_9**	**The Movement of each two pile heald frames**	**opposite**	**delayed**

Table (2) Properties of used yarns

Yarn kind / Yarn property		Warp pile yarns	Warp ground yarns	Weft yarns			
				1	**2**	**3**	**4**
Tex		**36.7*2**	**19.4*2**	**29.1*2**	**27.7*2**	**18.2*2**	**20.7*2**
The type of weft yarns		**Poly-acrylic**	**Polyester**	**Cotton**	**Polyester**	**Cotton**	**Polyester**
Twist factor	**Single**	**2.9**	**3.7**	**3.8**	**3.8**	**3.7**	**3.5**
	ply	**2.6**	**4.3**	**3.7**	**3.5**	**3.5**	**3.5**
Strength (gram)		**783**	**128.2**	**1110.4**	**1563**	**684.8**	**1590.2**
Elongation (%)		**24.8**	**15.02**	**6.65**	**24.01**	**5.76**	**18.46**

Table (3) Tearing strength for different factors combination.

Sample No.	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	grey		backed	
										warp	weft	warp	weft
1	-1	-1	1	-1	-1	-1	-1	-1	-1	40.1	48.7	31.8	45.1
2	-1	1	1	-1	1	1	-1	1	1	46.9	61	36.4	43.5
3	1	-1	1	-1	1	1	1	-1	1	54	23.9	38.2	15.9
4	1	1	1	-1	-1	-1	1	1	-1	33.2	8	27.2	7
5	-1	-1	1	1	1	1	1	1	-1	50.6	62.5	39	50.1
6	-1	1	1	1	-1	-1	1	-1	1	44.7	42.3	38	31.7
7	1	-1	1	1	-1	-1	-1	1	1	55.5	17.3	40.4	16.7
8	1	1	1	1	1	1	-1	-1	-1	51.5	10.5	46.5	15.5
9	-1	-1	-1	-1	-1	1	1	1	1	31.3	41	31.8	30.5
10	-1	1	-1	-1	1	-1	1	-1	-1	44.5	55	56	47.3
11	1	-1	-1	-1	1	-1	-1	1	-1	62.7	37.5	50.8	28.9
12	1	1	-1	-1	-1	1	-1	-1	1	36.6	8.4	29.3	7
13	-1	-1	-1	1	1	-1	-1	-1	1	50.1	58.2	42	42.5
14	-1	1	-1	1	-1	1	-1	1	-1	41.3	39.2	38.5	35.1
15	1	-1	-1	1	-1	1	1	-1	-1	43.2	12.9	34.7	13.3
16	1	1	-1	1	1	-1	1	1	1	59.8	18.1	47.9	10.8
17	-1	-1	1	-1	1	1	1	1	1	37.6	62.5	40.6	49
18	-1	1	1	-1	-1	-1	1	-1	-1	33.5	27.2	30.7	27.6
19	1	-1	1	-1	-1	-1	-1	1	-1	37.9	13	38.7	12.5
20	1	1	1	-1	1	1	-1	-1	1	45	12.1	51	10.8
21	-1	-1	1	1	-1	-1	-1	-1	1	42.6	48.2	41	44.9
22	-1	1	1	1	1	1	-1	1	-1	50.1	64.2	43.2	67.9
23	1	-1	1	1	1	1	1	-1	-1	49.5	27.3	46.3	27.2
24	1	1	1	1	-1	-1	1	1	1	38.8	8	47.5	7.1
25	-1	-1	-1	-1	1	-1	-1	-1	-1	48.9	51.8	39.5	46.9
26	-1	1	-1	-1	-1	1	-1	1	1	47.8	35.4	30.7	30.8
27	1	-1	-1	-1	-1	1	1	-1	1	30.8	10.9	33.6	9.9
28	1	1	-1	-1	1	-1	1	1	-1	66.4	19.5	61.3	10.9
29	-1	-1	-1	1	-1	1	1	1	-1	47.1	38.1	35	33.9
30	-1	1	-1	1	1	-1	1	-1	1	48.1	60.5	52.2	52.7
31	1	-1	-1	1	1	-1	-1	1	1	64.2	47	48.8	21.6
32	1	1	-1	1	-1	1	-1	-1	-1	57	12.9	51.8	8.9

A regression equation of the following form was proposed for the results.

$$Y=a_0+\sum_{i=1}^{n} a._i * X_i + \sum_{j>i}^{n}\sum^{n} a_{i.j} * X_{i.j}$$

Where Y_i- The tear strength of the i-th condition

a_0 , a_i , $a_{i.j}$, are the coefficients of the relation

X_i , the i-th factor under study

$X_{i.j}$, the interaction between the i- th and j- th factors.

Stepwise regression analysis had applied for determining a significant regression equation. The parameter is considered significant if p-value is lesser than 0.05.

The significant regression equations are:

A-Tearing strength models in warp direction.

Grey, $Y1=46.6+2.53X1-2.13X3+3.03X4+4.59X5-2.69X7+1.6X8+2.24X1.5$ $R^2=0.71$

Backed, $Y2=41.3+2.1X1+1.75X2-1.48X3+2.04X4+8.39X5-4.56X3.6+2.53X3.$ $R^2=0.72$

B. Tearing strength models in weft direction.

Grey, $Y_3=33.8-15.9X_1-3.7X_2+1.6X_4+8.65X_5-2.06X_6+1.92X_8$ $R^2=0.92$

Backed, $Y4=28.23-14.2X1-2.32X2+1.76X4+5.06X5-2.21X7-1.65X9-1.93X$ $R^2=0.92$

4. Discussion

Based on the above models, different factors affect tearing strength as follows:

4.1 Effect of the weft yarns type(X1)

Polyester weft yarns decreased the tearing strength of grey and backed fabrics in warp direction, and increased it in weft direction. This is because using Polyester weft yarns with Polyester warp yarns to make the ground of the fabric increased the friction, which accordingly, increased the force required to make Polyester warp yarns slip over them, and led to a reduction in tearing strength in warp direction. However, the high strength and extensibility of Polyester weft yarns increased tearing strength in weft direction. Using Cotton weft yarns acted *differently* than Polyester ones. Cotton yarns showed less tearing strength in weft direction and more tearing strength in warp direction of the fabric. This is because low strength and extensibility of weft cotton yarns reduced the tearing strength in the weft direction while the smooth surface of Cotton yarns gave the warp yarns more freedom to slip over them and this yield a higher tearing strength in warp direction.

4.2 Effect of weft yarn count (X2)

The less thick the weft yarns (30/2 Ne), the less the tear strength in weft direction. This is due to low strength and extensibility, when compared with thick yarns (20/2 Ne). However, the thinner the weft yarns, the higher the tear strength in warp direction. This is because the thin weft yarns increase the spaces between them in the fabric, and this allows more freedom for warp yarns to move and group together presenting bundles of warp yarns to the tear load. This result did not give a significant value in the warp direction for grey fabrics.

4-3 Effect of no. of picks /cm (X3)

Increasing the numbers of picks /cm decreased tearing strength in warp direction because of increasing the density of the fabric, which is to have more compact and close fabric that lead to more restriction on yarns and less tendency to slip**.** However, the effect of number of picks/cm on tearing strength in weft direction of the fabric did not show significant value.

4-4 Effect of warp ground tension levels in the two warp beams (X4)

Difference in tension levels in both two-warp beams resulted in a higher tearing strength in warp and weft directions of grey and backed fabrics. This is in comparison with equal tension levels on warp yarns since the equal tension levels on both warp beams make the yarns in alignment to the tear load. However, the different tension levels on warp beams act differently, since it forms groups of warp yarns on both directions of the fabrics, which give more extensibility and more freedom to move, resisting the tearing strength under load.

4-5 Effect of the ground weave structures(X5)

Using 2/2 warp rib structure for ground weave gave higher tear strength in both directions of the fabric compared with the use of 1/1 plain weave structure. This result is in accordance with Lord& Mohamed (4) and Taylor (7) because of the formation of groups of yarns woven together.

4-6 Effects of pile shape of beam No.1 (X6) and beam No.2 (X7) yarns

V-pile shaped yielded higher tearing strength in both directions of the fabrics than W- shape. This is because each pile tuft with V-shape is anchored by one base filling which make each filling free of the tear load. However, each pile tuft with W- shape is anchored by three base fillings at least. This leads to anchoring among the three fillings and puts them in alignment in front of the tear load, this means less tearing strength. The effect of pile shape in warp direction of the fabric on tearing strength is indicated directly in grey fabrics (Y_1), while it interacted with another factor (X_3) (No. of picks) in backed fabrics (Y_2).

4-7 Effect of shifting the designation of the pile (X8).

Shifting the designation of the pile increased the tearing strength of the grey fabrics in both directions compared with the similar fabrics which are produced without shifting the designation of the pile. This is because the number of pile tufts on the wefts with shifting the designation of the pile is less, which give the wefts more freedom to move under loading.

4-8 Effect of moving the two-pile heald frames (X9).

Moving each two- pile heald frames of the pile beam yarns in opposite on the same two picks in the shedding (at one cycle of the machine) made the tearing strength in both directions of the backed fabrics higher than when it is compared with delaying the movement of one group of them on the second pick(the second cycle of the machine). That gives different contribution for pile on the surface of the fabric, as shown in fig.(3); which means more friction between two pile tufts together and between them with some wefts, and so less tearing strength. However this effect was not significant in both directions of grey fabrics

From the above equations, it can be detected that the factors X_1 & X_2, as an example, have opposite sign in case of warp and weft tearing strength. Since the tear serviceability of the fabric acts as a compound of warp and weft, so the regression equation of their geometrical mean was determined. Determined coefficients of the regression equations, when using the geometrical mean of the tearing strength, indicated the same effect for both grey and backed fabrics. From that polyester weft yarns, different tension levels on warp ground yarns, 2/2warp rip structure, and Pile shifting increase the tearing strength. While coarser count and pile shape decrease tearing strength. The regression equations were as follows:

Tearing strength models for the geometrical mean:

Grey, $Y5= 37.83-8.75X1-2.66\ X2+2.13\ X4+7.47\ X5-2.64\ X6+1.78\ X8-2.16X1.2$ $R^2=0.9$

Backed, $Y6=32.3-8.26X1+1.82\ X4+4.85\ X5-1.89X1.2+1.67X2.6$ $R^2=0.88$

5-Conclusion

The goal here is to isolate the primary factors that contribute to the tearing strength of pile fabrics, produced on face-to-face looms with dobby device (three positions), which are yarn type and count, *pick density*, pile and ground weave structures, and tension levels on warp ground yarns.

These factors were predicted to be effective on the yarn strength, extensibility, spacing or dense of fabric, and fractional constraints at yarn interlacing which are effective on tearing strength. These factors were analyzed, assessed for relevance, and integrated into predictive models. From the results as described in this work, it should be possible to evaluate the tearing strength of pile fabrics more scientifically and to design high tearing strength fabrics. This could be useful both for analysis of pile fabrics already *constructed on* dobby looms with three positions, and for design of new pile fabrics. It is obvious that tearing strength is affected to a great extent by type and count of weft yarns, *pick* density, ground structure and tension on ground yarns .Lesser effects are obtained due to pile shape, pile designation shifting and moving system of the pile yarn groups.

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