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Effect of Yarn Properties on the Pilling of Cashmere Knitted Fabric

Abstract
The factors influencing fabric pilling include the fibre properties, yarn properties, fabric structure and wear condition. As an expensive textile material, cashmere fibre exhibits a small diameter, short length and smooth surface. The pilling of cashmere knitted fabric has attracted the attention of consumers, manufacturers and researchers. In this work, the effect of yarn properties on the pilling rates of cashmere knitted fabric is investigated. The results showed that the dye colour of cashmere fibers is of primary importance for the pilling rates of cashmere knitted fabric. The relationship between the pilling rates and yarn properties was obtained by using optimal scaling regression analysis. The pilling rates of different coloured fabrics were compared.

Key words: *pilling, cashmere, yarn properties, cashmere dyed color, optimal scaling regression analysis.*

Introduction

Fabric pilling is a well known phenomenon. Pill formation is a self-limiting process involving several distinct stages. Generally, the pilling mechanism is often summarised as three broad events: fuzz generation, entanglement of fuzz into pills and pill wear off [1]. Many factors influence the rate and extent at which each stage occurs. Previous research works have identified many factors that contribute to fabric pilling. These factors constitute every stage of the fibre to fabric processing chain and include fibre properties (type, diameter, tensile strength, fatigue, bending rigidity, initial modulus), yarn properties (type, twist factor, blend ratio) and fabric structures. Fabric pilling problems have not yet been solved [2]. Conventional ring spun yarns have many fibres that protrude from the yarn surface, causing yarn hairiness. Projecting fibres, or yarn hairiness, are free fibre ends forming fabric surface fuzziness that subsequently develops into pills. Hence, it is common that an increase in yarn hairiness leads to a higher propensity to pill formation [3 - 5]. As regards yarn properties influencing pilling, Richards [6] found that an increase in pilling mass occurred when the linear density of the yarn was reduced. Cooke [7] found that an increase in yarn twist results in a decrease in fibre migration, fuzz generation and pilling. As for pure wool knitwear, where a soft bulky yarn is desired, an increase in pilling generally stems from the high surface migration of fibres when exposed to an abrading action [8].

Cashmere, an expensive textile material, is mainly used for knitted fabric. Because of the small diameter, short length and smooth surface of cashmere fibre [9], the pilling of cashmere knitted fabric is a serious problem and has attracted the attention of consumers, manufacturers and researchers. Considering that the interaction between individual factors is complex owing to the nature of pill formation, an artificial neural network (ANN) was used to model the relationship between the many fibre, yarn, fabric attributes and the pilling propensity [10 - 13]. In this work, the effect of cashmere yarn properties on the pilling of cashmere knitted fabric was investigated using the optimal scaling regression analysis method.

Experimental

Samples

64 cashmere yarns and knitted fabrics were supplied by 6 cashmere enterprises in China. All yarns were of dyed cashmere fibres. The knitted fabrics were jersey stitch; the fabric density was 10.2 ~ 11.5 yarns /inch. The colours of dyed cashmere fibre can be termed thick, medium and thin according to the needs of consumers. The yarn linear density of the design was 38.46 tex for the yarns, the actual yarn linear density 37.3 tex ~ 39.5 tex, the yarn linear density of CV from 0.84% to 4.45%, the yarn tensile strength from 215.70 cN to 368.0 cN, and the yarn evenness was from 8.34% to 12.21%.

Pilling rates test

The pilling rates were tested using ICI's Pilling Box. The test time was 2 hours. The pilling of the fabrics was tested and rated by an experienced test person. The pilling standards used for rating the fabrics had the following scales: 5: no pills, 4: slight pilling, 3: moderate pilling, 2: severe pilling, 1: very severe pilling.

The pilling rates of the cashmere knitted fabrics were the followings: 3 rates (23 samples), 4 rates (34 samples), and 4.5 rates (7 samples).

Analysis and discussion

Variables definition

The variables in this work were defined before the analysis. ***Table 1*** shows the result of definition.

The pilling rate (Y) is a dependent variable, whereas X_1, X_2, ..., X_{10} and X_6X_7 are independent variables, respectively.

The pilling rates (Y) is an ordinal variable; X_1, X_2 are nominal variables, and X_3, X_4, ..., X_{10} and X_6X_7 are numeric variables.

Because the variables include an ordinal variable, nominal variable and numeric variable, the original setting mode of the variables is random. The maximum iteration number is 200.

Table 1. Variable definition.

variable	definition
Y	pilling rates of knitted fabric
X_1	colour of dyed cashmere
X_2	cashmere spinning enterprise
X_3	actual yarn linear density, tex
X_4	actual yarn linear density CV, %
X_5	yarn tensile strength, cN
X_6	actual yarn twist, T/m
X_7	actual yarn twist CV, %
X_8	yarn breaking elongation, %
X_9	yarn evenness, %
X_{10}	density of knitted fabric, yarn/inch
X_6X_7	interaction of actual yarn twist and twist variance coefficient

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Statistical analysis

The relationship between yarn properties and pilling rates are analysed by using the optimal scaling regression method [14]. The original variables are transformed using the nonlinear transformation method, and then the equation is obtained by repeat iterating.

The convergence level is achieved after 184 iterations, where R is 99.5%, and R^2 is 99%. By adjusting the optimal scaling, R^2 changes into 94%.

At a significance level of 5%, all the P values of the independent variables are less than 0.0001 except that of the actual yarn twist. At a significance level of 0.1%, all the independent variables have a statistical significance except the variables of the actual yarn twist and yarn breaking elongation.

If the variables of the actual yarn twist and yarn breaking elongation are removed from the equation, the convergence level is achieved after 164 iterations.

After the transformation, the correlation coefficients of the independent variables decrease, whereas the correlation coefficients of X_2, X_5, X_8 and X_9 increase, in which R is 99.5% and R^2 99.1%.

The standardised coefficient of the variables in the equation is shown in ***Table 2***. The total significance of the well-chosen variables is less than 0.0001, which negates the assumption that the partial regression coefficient is 0. Hence, the equation has statistical significance. Based on the coefficients and definition of the original variables, it can be concluded that the lower the yarn linear density and yarn evenness, the higher the pilling rates and yarn tensile strength are. Because the dye colour of cashmere and cashmere spinning enterprises are nominal variables, their standardised coefficients reflect the degree of influence only.

Based on the standardised coefficient value, it is shown that the dye colour of cashmere has a serious influence on pilling rates when the yarn twist and fabric density are set at a certain level. The actual yarn linear density has little influence on pilling rates because the yarn linear density of the design is 38.46 tex for all yarns. The order of independent variables influencing pilling rates, from severe to slight, is as follows: the dye colour of cashmere, the interaction of the

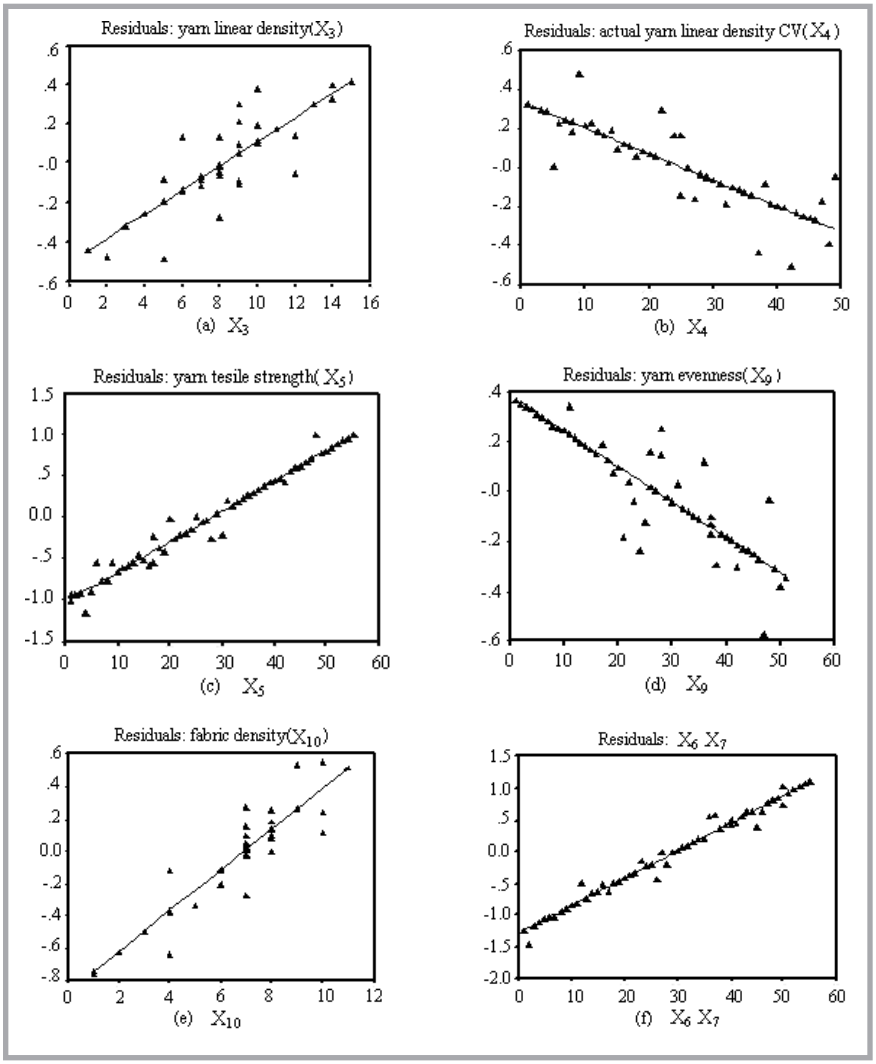

Figure 1. *Residuals plot; (▲) Residuals labelled by case number.*

Table 2. *Coefficients.*

Independent variable	standardised coefficient		d_f	F	Sig.
	Beta	Std. Error			
X_1	1.314	0.042	40	1000.530	0.000
X_2	0.561	0.034	5	271.333	0.000
X_3	0.166	0.030	1	31.157	0.000
X_4	-0.108	0.031	1	33.995	0.000
X_5	0.588	0.035	1	275.625	0.000
X_9	-0.202	0.034	1	36.445	0.000
X_{10}	0.266	0.033	1	65.435	0.000
X_6X_7	0.702	0.037	1	352.176	0.000

Table 3. *Correlations and tolerance.*

Independent variables	Correlations			Importance	Tolerance	
	Zero-order	Partial	Part		After transformation	Before transformation
X_1	0.597	0.994	0.880	0.792	0.449	0.781
X_2	0.289	0.979	0.458	0.164	0.669	0.546
X_3	-0.019	0.850	0.155	-0.003	0.874	0.901
X_4	0.201	-0.860	-0.162	-0.037	0.815	0.726
X_5	-0.089	0.979	0.462	-0.053	0.618	0.792
X_9	0.289	-0.867	-0.168	-0.059	0.690	0.772
X_{10}	0.391	0.919	0.225	0.105	0.719	0.783
X_6X_7	0.127	0.983	0.522	0.090	0.553	0.791

actual yarn twist and twist CV, the yarn tensile strength, the cashmere spinning enterprise, knitted fabric density, yarn evenness, the actual yarn linear density. The equation of yarn properties influencing pilling rates is following as:

$$Y = 1.314\,X_1 + 0.561\,X_2 + \\ + 0.166\,X_3 - 0.180\,X_4 + 0.588\,X_5 + \\ - 0.202\,X_9 + 0.266\,X_{10} + 0.702\,X_6X_7$$

The definitions of Y and X_i are shown in ***Table1***.

The correlation index and tolerance index of all independent variables are shown in ***Table 3***. All tolerances before transformation are more than 0.4. After transformation, all tolerances are more than 0.5. From the importance of independent variables, it is shown that the dye colour of cashmere is of primary importance in the equation, followed by the interaction of the actual yarn twist and its CV. Based on the partial correlations, it is shown that there is a good relationship between the independent variables (X_i) and the dependent variable (Y). The correlation between the dye colour of cashmere and pilling rates is the highest, followed by the interaction of the actual yarn twist and its CV, the yarn tensile strength, the cashmere spinning enterprise, fabric density, yarn evenness, the actual yarn linear density CV and the actual yarn linear density.

Table 4. *Yarn properties.*

Dyed color	Tensile strength, cN	Breaking elongation,%	Actual twist, T/m	Actual twist CV, %	Yarn evenness, %	Fabric density, yarn/inch
lilac	359.6	11.6	210	5.46	7.46	8
red	333.9	13.9	211	5.86	7.04	8
light tan	277.1	14.4	265	3.27	8.73	10.5
black	237.8	11.3	262	6.20	8.44	10.5
dark red	177.8	9.8	318	8.34	10.14	12.9
white	189.5	19.6	316	5.39	9.06	12.9

Figure 1 shows the residual plots of the independent variables. It is shown that that all the residual plots are linear. Hence, the normal distribution assumption of the error is reasonable.

Yarn properties and fabric pilling

The dye colours of the cashmere fibres were lilac, red, light tan, black, and dark red. The yarn linear density of the lilac cashmere and red cashmere was 55.6 tex × 2, the yarn linear density of the light tan cashmere and black cashmere 38.5 tex × 2, and the yarn linear density of the dark red cashmere and original cashmere (white color) was 27.8 tex × 2. And all the yarns were produced by a spinning company. The yarn properties are shown in ***Table 4***.

The pilling rates of cashmere knitted fabrics of different colours are shown in ***Figure 2***. The result for the worn-off fibre weight of the fabric during the pilling test is shown in ***Figure 3***. The results show that pilling rates are low for fabrics of thick dye colour, and pilling rates rise when the yarn tensile strength is high under the same yarn linear density. For the same yarn linear density, the worn-off fibre weight of fabrics of thick dye colour rises, whereas the worn-off weight is lower for a high yarn tensile strength. Hence, the equation shows statistical significance.

For cashmere fibre dyeing, the dyeing temperature, dyeing time and pH are three important factors. ***Figure 4*** show the dyeing technology curves of cashmere dyed with thin colours and cashmere fibres dyed with thick colours, respectively. For the former, the dyeing time is short, whereas for the latter, the dyeing time is long. Hence, the properties of cashmere fibres dyed with thick colours have more damage compared with those dyed with thin colours .

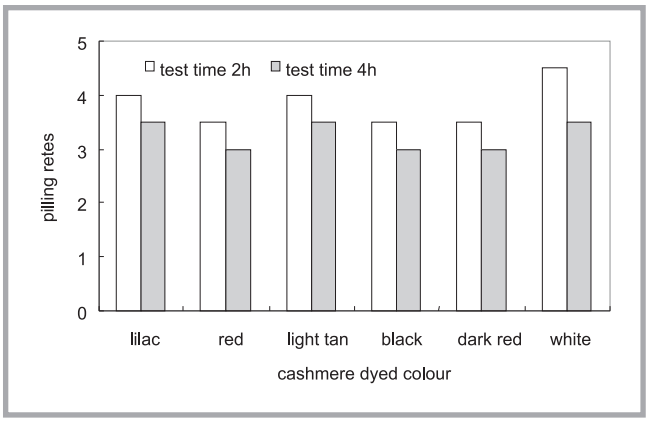

Figure 2. *Pilling rates of knitted fabric of various colour.*

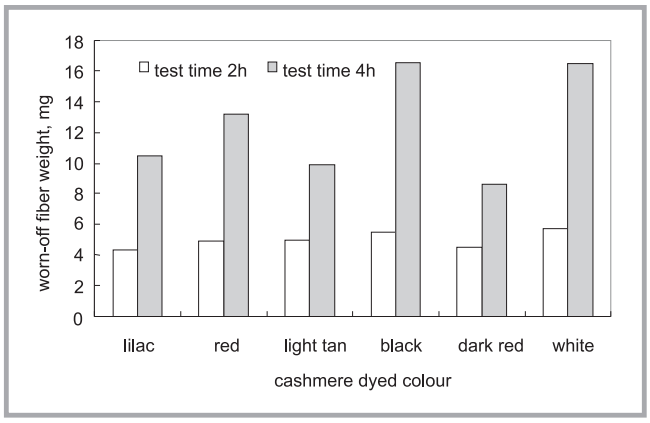

Figure 3. *Worn-off fibre weight of knitted fabric of various colour (test time 2 hrs).*

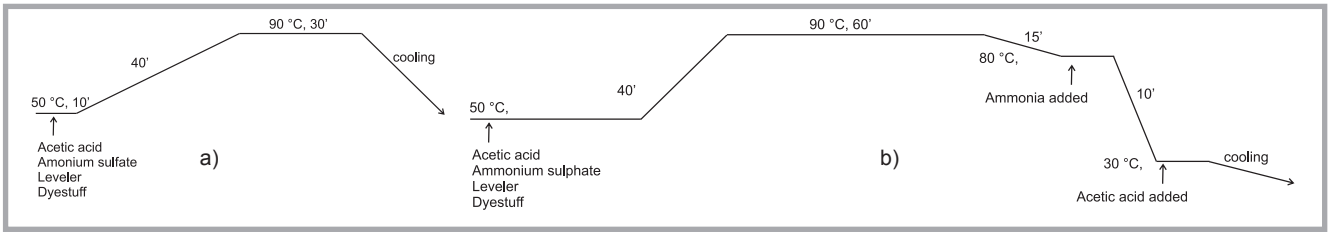

Figure 4. *Dyeing technology for: a) weak acid dyestuff, and b) reactive dyestuff.*

Conclusions

The yarn breaking elongation has little effect on the pilling rates of cashmere knitted fabric. The dye colour of cashmere fibres is of primary importance in influencing fabric pilling rates., followed by the interaction of the actual yarn twist and its CV, the yarn tensile strength, the cashmere spinning enterprise, fabric density, yarn evenness, the actual yarn linear density CV, and the actual yarn linear density The pilling rates decrease and the worn-off fibre weight rises for fabric dyed with a thick colour.

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Editorial note

Appendix is available after contacting the authors of the article.

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