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Performance Properties of Half-bleached Weft Knitted Fabrics Made of 100% Cotton Ring Yarns with Different Parameters

Učinkovitost lastnosti polbeljenih votkovnih pletiv, izdelanih iz 100-odstotnih bombažnih prstanskih prej z različnimi parametri

Original scientific article/*Izvirni znanstveni članek*
Received/*Prispelo* 8-2020 • Accepted/*Sprejeto* 2-2021

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Abstract
Knitted fabrics are distinguished by their outstanding comfort for clothing and for their rapid mass production. Though cotton knitted fabrics can provide better comfort, their physical appearance and service life are affected by many factors, and they have a propensity for pilling, abrasion and snagging. The main goal of this research work was to investigate the effect of yarn parameters on the abrasion, pilling and snagging resistance of half-bleached knitted fabrics. Six knitted fabrics were manufactured from 100% cotton carded ring yarn with a linear density of 21, 25, and 30 tex, with two yarn twist levels for each linear density. Except for yarn linear density and twist, the remaining yarn and machine parameters were constant, including fabric manufacturing. The knitted fabrics were treated using a half-bleach treatment before property evaluation. The results showed that knitted fabric made from a finer count of 21 tex with a higher yarn twist of 920 m^{-1} had the highest mass loss ratio of 2.12–10.76%, and the lowest abrasion resistance of 89–97.88% between 5,000 to 20000 abrasion cycles. The highest abrasion resistance of 96.4–98.9% (mass loss ratio of 1–3.5%) was recorded for a single jersey knitted fabric made from coarser yarn (30 tex) with the lower twist of 826 m^{-1}. The abrasion resistance of knitted fabrics was significantly affected by the thickness of the fabric, while regression analysis proved that fabric thickness and mass loss ratio had very good correlation, with an adjusted R^2 value of 93.8%. The snagging resistance of knitted fabrics increased as yarn twist and fineness increased. Pilling propensity increased as yarn linear density increased and twist decreased. Linear regression results revealed that yarn linear density and twist were highly correlated to abrasion resistance (mass loss method) at an adjusted R^2 value of 98.6% or 0.986 after 20,000 rubs.
Keywords: yarn parameters, knitted fabrics, half-bleached, abrasion, pilling, snagging resistance

Izvleček
Izjemna udobnost pletenih oblačil in hitra masovna proizvodnja pletiv sta znani. Čeprav bombažna pletiva zagotavljajo udobje, pa sta njihov estetski videz in doba trajanja odvisna od številnih dejavnikov, ki vodijo v nastanek pilinga, drgnjenje in izvlečenje zank. Glavni cilj te raziskave je bil proučiti vplive parametrov preje na odpornost proti drgnjenju,

pilingu in izvlečenju zank polbeljenih pletiv. Izdelanih je bilo šest pletiv iz 100-odstotnih bombažnih mikanih prstanskih prej s finočo 21 tex, 25 tex in 30 tex z dvema različnima stopnjama vitja. Preostali parametri izdelave prej in pletiv so bili enaki. Pletiva so bila pred oceno lastnosti polbeljena. Rezultati so pokazali, da je pletivo, izdelano iz finejše preje 21 tex z višjim vitjem 920 m^{-1}, pri 5000 do 20.000 ciklih drgnjenja izgubilo največ mase, in sicer 2,12–10,76 %, ter imelo najnižjo, 89–97,88-odstotno odpornost proti obrabi. Najvišja, 96,4–98,9-odstotna odpornost proti drgnjenju (masa zmanjšana za 1–3,5 %), je bila zabeležena pri enojnem jerseju, izdelanem iz preje 30 tex z vitjem 826 m^{-1}. Na odpornost proti drgnjenju je močno vplivala debelina pletiv. Regresijska analiza je pokazala, da sta debelina in zmanjšanje mase med seboj močno soodvisna, kar je potrdil 93,8-odstotni korelacijski koeficient, R^2. Odpornost pletiva proti izvlečenju zank se je povečala z vitjem in finočo preje. Nagnjenost k pilingu se je povečala, ko se je finoča preje zvišala in se je vitje znižalo. Rezultati linearne regresije po 20.000 drgnjenjih (metoda zmanjšanja mase) so pokazali korelacijo finoče in vitja preje z odpornostjo proti drgnjenju, saj je korelacijski koeficient, R^2, znašal 98,6 odstotka ali 0,986.
Ključne besede: parametri preje, pletivo, polbeljeno pletivo, drgnjenje, piling, odpornost proti izvlečenju zank

1 Introduction

Abrasion resistance and pilling performance are two of the most important mechanical characteristics of fabrics [1] and a factor in virtually every textile application. They are also a major purchasing requirement from the consumer's viewpoint. The abrasion resistance of textile materials is affected by many factors in a very complex and poorly understood manner [2]. Market studies have shown that evaluations of consumer quality requirements are related to abrasion resistance [3]. Abrasion is the gradual removal of fibres from yarns, and is influenced by fibre cohesion in yarns [4]. Kalaoglu et al. and McCord [3, 5] stated that the abrasion resistance of textile materials is affected by many factors, such as fibre content, fibre fineness, yarn linear density, yarn type, weave, fabric thickness, finishes, etc. Abrasion first modifies the fabric surface and then affects the internal structure. Similarly, the pilling of knitted fabrics is a persistent and serious problem for the clothing industry [6]. Many parts of clothing, such as collar, cuffs, and pockets are subjected to wear in use, which limits their serviceability. Pilling not only reduces appearance and comfort properties, but also affects the service life of textile products [7]. Uyanik and Topalbekiroglu studied the effects of knit structures on the pilling resistance of knitted fabrics made from the same cotton yarn. The results revealed that single jersey has a lower pilling resistance than fabrics with tuck stitches, while knit structures with larger pores show higher a resistance to pilling. Some authors studied the relationship between fibre, yarn and wool single jersey and rib knitted fabrics on pilling property. The prediction of the pilling tendency of those wool knits was developed by artificial neural network modelling (ANN) [8, 9].

In addition, dyeing and finishing processes reduce the pilling resistance of knitted fabrics [10]. Other authors have researched the effect of wet processing on cellulosic knitted fabrics, and the model suggests that the ends of fibres come out from yarns by mechanical abrasion due to low fibre-fibre friction [11]. Candan studied the pilling and abrasion properties of different knitted fabrics made from ring and open-end spun cotton yarns, and 50/50 cotton/polyester yarns. The results showed that, unlike plain jersey fabrics, Lacoste fabrics perform very well and that fabrics knitted from open-end spun yarns generally have a lower propensity to pilling [12]. Akaydin and Can stated that the abrasion resistance and pilling performance of interlock fabrics were higher than jersey fabrics, those of dyed fabrics higher than raw fabrics, and those fabrics produced from compact yarns were higher than fabrics produced from ring yarns [13]. Another researcher investigated the effects of fibre type, and single and ply yarns on the abrasion and pilling resistance of socks. The results indicated that the abrasion resistance of socks increased with use of coarser yarn or thicker yarn, the addition of polyester, and the addition of polyamide or elastic yarns to the structure [14]. Knitted fabrics with interlock, rib and single jersey structures made from compact and conventional ring yarns and their physical properties were investigated, and compared with each other before and after printing processes. It was found that no statistical differences were observed with regard to weight, abrasion resistance, colour efficiency and rubbing fastness [1].

A previous study reported that the fibrous composition and thickness of materials (up to 6%), as well as washing and softening (from 33% to 67%) change the pilling resistance of knitted fabrics [15]. Daiva studied the pilling resistance of single jersey, rib and interlock knitted fabrics made from PES yarns, cotton yarns and cotton yarns combined with PU yarns. The results found that 2×2 rib knitted fabric has a better pilling resistance than interlock, 1×1 rib and plain knitted fabric because of the reduced operating surface area. Fabrics knitted from PES (polyester) yarns or those PES yards blended with cotton yarns have a worse visual appearance than fabrics knitted from pure cotton yarns because PES fibres are resistant to malformed pills due to their exceptional strength [6]. A 100% cotton single jersey knitted fabric made from a combed ring yarn with a linear density of 19.7 tex, and a different stitch position and length, was studied, and the results revealed that stitch density (wales/cm and course/cm) and mass per unit area, bursting, pilling and abrasion resistance decrease as stitch length increases [16, 17]. Single jersey knitted fabrics with various numbers and position of tuck stitches were made from glass yarn using a flat knitting machine. The findings proved that fabric thickness increased and air permeability decreased as tuck stitches increased [18]. The effect of rubbing fastness on single jersey knitted fabrics made of combed ring-spun and compact cotton yarns was researched. The reports showed that knitted fabrics made from compact and comb yarn were similar in terms of rubbing property in a dry state. However, single jersey knitted fabrics made from ring yarn have a greater rubbing resistance in a wet state due to the high porosity of the ring yarn fabrics, which allows water molecules to penetrate [19, 20].

Numerous researchers have stated that the end-use properties of clothing, such as pilling effect and abrasion resistance, are influenced by material type, fibre fineness, yarn linear density, yarn strength, yarn hairiness, fabric structure and surface density [2, 21–24]. A comparison of pilling and abrasion properties of knitted fabrics was performed for different spinning yarns, such as ring, compact and rotor yarns [25–30]. The effects of washing and drying [1] as well as finishing and dying [31, 32], were also investigated. Knitted fabrics from compact yarns have a higher pilling and abrasion resistance than ring and rotor yarns, while the abrasion resistance of knitted fabrics from ring-spun yarns was slightly better than open-end spun yarns [33].

As shown in a review of literature, many researchers have studied the effects of yarn structure, linear density, twist and knitted structure on the abrasion, pilling, tensile and tear strength properties of fabrics. Most of the studies were done at the greige fabric level and based on a comparison based on different spinning methods. However, the effects of yarn properties on fabric snagging resistance have not been thoroughly addressed. The aim of this study was to investigate the influence of ring yarn parameters (by varying yarn linear density and twist) on the pilling, abrasion and snagging resistance of half-bleached knitted fabrics.

2 Materials and methods

2.1 Materials

Six single jersey knitted fabrics were produced from 100% cotton carded ring yarn counts of 21 tex with two twist levels of 920 m^{-1} and 905 m^{-1}, 25 tex with twist levels of 890 m^{-1} and 860 m^{-1}, and 30 tex with twist levels of 847 m^{-1} and 826 m^{-1}.

2.2 Methods

Each of the three yarns with two different twist levels were produced using a ring spinning system (RIETER-G35) manufactured by Bahir Dar Textile Share Company. All yarns were spun from the same fibre mix with a micronaire value of 4.23, a maturity of 0.85, an upper half mean length (UHML) of 29.86 mm, a uniformity index (UI) of 84.5%, a strength of 30.4 cN/tex, an elongation of 7.4%, a short fibre content of 6.7% and a trash grade of three. Yarn linear density and yarn twist were measured according to the ES ISO 2060 and ASTM D1422 test methods, respectively. Six knitted fabrics were manufactured using those developed yarns with incremental twist levels. Except for yarn linear density with different twist levels, the remaining parameters were constant and the knitted fabrics were produced on the same SHIMA SEIKI® (model – SES 122 FF, gauge 7) flat knitting machine at the Technical University of Liberec in the Czech Republic. The machine settings, such as machine speed, loop length, and horizontal and vertical density per centimetre were kept constant for all fabrics. The yarn and fabric characteristics are presented in Table 1.

Chemical treatments

Hydrogen peroxide (H_2O_2) based half-bleach combined treatment was carried out for knitted fabrics using a winch machine. The fabric and water solution were prepared at a material to liquor ratio (MLR) of 1:5, and hydrogen peroxide (H_2O_2), sodium silicate (Na_2SiO_3), sodium hydroxide (NaOH) and a wetting agent of 4%, 2%, 3%, and 0.5% of fabric weight, respectively. Knitted fabrics were treated at a temperature of 95 °C for 90 minutes at a machine working speed of 40 m/minutes.

Abrasion resistance

The abrasion resistance of the knitted fabrics was measured using two methods according to ES ISO 12947-1 (appearance change method) at 5,000 cycles and ES ISO 12947-3 (mass loss method) using a Martindale Abrasion and Pilling device (Mesdan-Lab, Model 2568). The mass loss ratios of knitted fabrics were recorded after 5,000, 7,500, 10,000, 15,000 and 20,000 cycles of the Martindale Abrasion and Pilling device. Pressure loading of 9 kPa was used during testing for both methods (1 and 3).

Pilling resistance

The pilling properties of knitted fabrics were measured using two different methods according to ES ISO 12945-2 after 5,000 cycles using a Martindale Abrasion and Pilling device. The second evaluation was based on ES ISO 12945-1 at 18,000 cycles according to the ICI Pilling-Box method using a Mesdan-Lab device, model no. 1006). Finally, the pilling grade was rated using the EMPA (SN 19825) photographic standard.

Snagging resistance

A snagging test was evaluated according to ASTM D3939 after 600 revolutions using an SDL ICI Mace snagging tester (model no. P22668). The test specimens were graded using the relevant photographic standard.

Statistical analysis

To determine the analysis of variance and significant test, SPSS version 25 for Windows statistical software was used. Regression analysis was performed using Origin Lab software (version 9.6.5) to determine the correlation of factors (yarn parameters) and response (fabric properties).

3 Results and discussion

Table 1 presents the properties and characteristics of the yarns used and the developed knitted fabrics. Except for yarn count and twist levels, all knitted fabrics were produced using the same yarn property, knit type and thread density.

Structural properties of knitted fabrics

The structural parameters of the knitted fabrics, such as stitch density, loop length, cover factor, thickness and fabric weight were tested and the results are presented in Table 1.

The fabric cover factor K is defined as the proportion of the fabric area covered by actual yarn and expressed using equation 1.

$$K = \frac{\sqrt{\mathrm{Tt}}}{\ell} \quad (1)$$

where T_t represents linear density (tex) and ℓ represents loop length.

Effects of yarn parameters on abrasion resistance (appearance change)

As seen in Figure 1, the abrasion resistance (appearance change) of knitted fabrics declined from fabric K1 to K6. This is probably because individual fibres and neps were not firmly held in the yarn cross-section as turns per meter were decreased. Knitted fabrics made from lower twist yarns had a significant abrasion effect (appearance change) since the

Table 1: Yarn and knitted fabric characteristics

Fabric code	Yarn linear density (tex)	Twist (m^{-1})	Knit type	Loop length (mm)	Cover factor (K)	Stitch density (stitch/cm) (horizontal/ vertical)	Thickness (cm)	Mass per unit area (g/m^2)
K1	21	920	Plain	4.10	0.96	9/12	0.071	184
K2	21	905	Plain	4.10	0.98	9/12	0.075	189
K3	25	890	Plain	4.12	1.21	9/12	0.082	196
K4	25	860	Plain	4.11	1.26	9/12	0.086	203
K5	30	847	Plain	4.10	1.37	9/12	0.091	211
K6	30	826	Plain	4.08	1.44	9/12	0.096	224

presence of hairiness and neps were high in lower twist yarns. As is evident from Figure 1, fabrics K4, K5 and K6 from coarser yarn counts of 25 tex and 30 tex with lower twists of 860 m^{-1}, 847 m^{-1}and 826 m^{-1} had a slightly poor abrasion resistance grade in surface appearance. As stated above, this is because fibres in the yarn cross-section are not held firmly and are thus easily pulled by the abradant. As seen in Table 2, the statistical analysis also confirmed that abrasion resistance in the appearance change method resulted in a significant change at an F-value of 13.000 and P-value of 0.033. If the P-value is greater than 0.05, this means the samples have similar properties, while the opposite is true if the P-value is less than α value of 0.05.

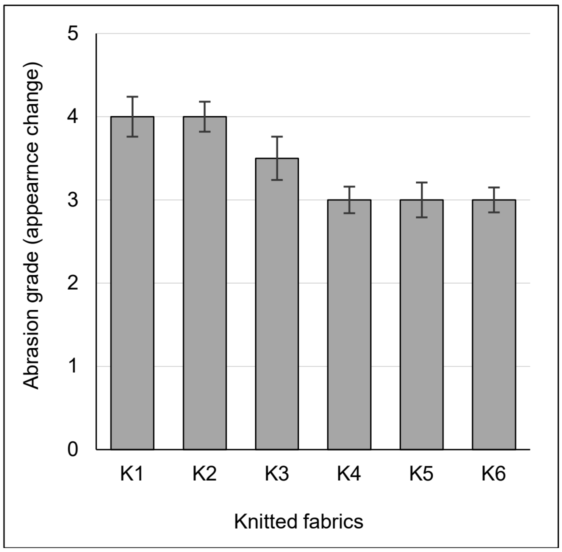

Figure 1: Abrasion resistance of knitted fabrics using the appearance change method

Twist is an important parameter affecting abrasion. At low twist levels, it was observed that fibres can be easily pulled from the yarn cross-section and that the resistance grade was reduced at 5,000 rubs. At high twist levels, however, the fibres are held more tightly, but the yarn is stiffer, so it is unable to distort under pressure when it is abraded. The findings of this study are in line with Saville's report [4]. Multiple regression analysis showed that the studied yarn parameters have a positive correlation with the abrasion resistance (appearance change) of knitted fabrics at an adjusted R^2 of 0.801. The adjusted R^2 value is an indication of the correlation of yarn properties (factors) and fabric characteristics (responses). When the adjusted R^2 value increases or decreases to 1 or –1, this indicates a strong correlation between them [34].

Effects of yarn parameters on abrasion resistance (mass loss)

As is evident from Figure 2, the knitted fabric weight mass loss ratio was increased as abrasion cycles increased in all fabrics. Nevertheless, the abrasion resistance increased as yarn count (tex) increased and yarn twist decreased. On the other hand, finer counts and higher twist yarns resulted in fabrics with thinner thickness, which had a high tendency to be abraded quickly. This, in turn, this led to higher mass loss ratio. As seen in Figure 2, knitted fabrics made from 30 tex with a yarn twist of 847 m^{-1} have a higher abrasion resistance of 96.4–98.9% (mass loss ratio of 1–3.5%) between 5,000 to 20,000 abrasion cycles than other developed fabrics. Knitted fabrics made of 25 tex with a twist per meter (TPM) of 890 m^{-1} and 860 m^{-1} demonstrated moderate abrasion

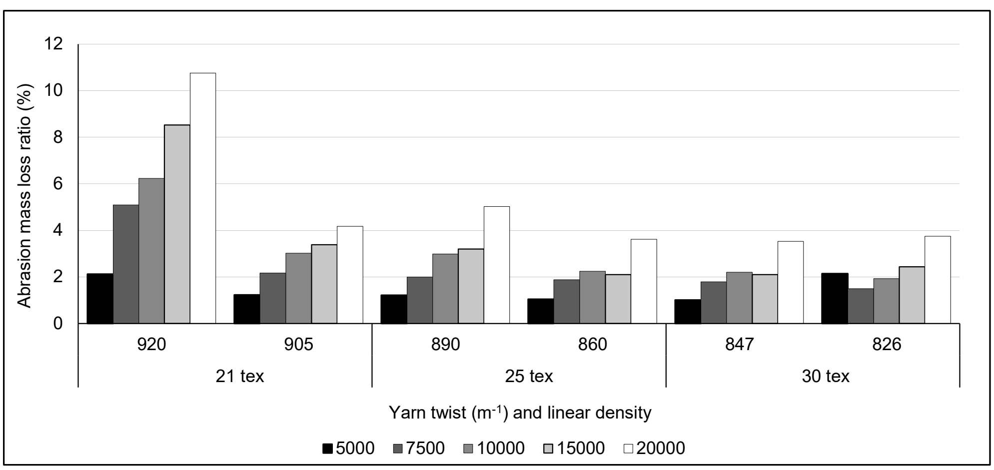

Figure 2: Abrasion results of knitted fabrics using the mass loss method (at 5,000, 7,500, 10,000, 15,000 and 20,000 rubs)

resistance, while knitted fabrics made from a finer yarn count of 21 tex with the highest yarn twist of 920 TPM demonstrated the highest mass loss ratio of 2.12–10.76% or an abrasion resistance of 89–97.88%. For this reason, fabrics from coarser yarn are thicker and bulky, and will require a great deal of time and a higher number of abrasion cycles to lose their original mass. These findings inveterate an earlier report by Kalaoglu and Onder [5].

As illustrated in Table 2, the statistical analysis proves that the abrasion resistance (mass loss method) of knitted fabric resulted in a insignificant change at a P-value of 0.660 after 5,000 rubs, and a significant change at P-values of 0.038, 0.000, 0.010 and 0.008 after 7,500, 10,000, 15,000 and 20,000 rubs, respectively. The results showed that the correlation of yarn parameters and abrasion resistance (mass loss method) was low at an adjusted R^2 value of 0.242 after 5,000 rubs. On the other hand, yarn twist and count were highly correlated with abrasion resistance at an adjusted R^2 value of 98.6% or 0.986 after 20,000 rubs. As observed from Table 1 and Figure 2, fabric thickness affects the abrasion resistance of knitted fabrics because thin fabrics withstand damage during friction for an extended period, and vice versa for thicker fabrics. The regression analysis proves that fabric thickness and abrasion mass loss are directly proportionate and correlated with an adjusted R^2 value of 84.3%.

Effects of yarn parameters on pilling resistance

Table 3 illustrates the pilling resistance of knitted fabrics using the Martindale and ICI Pilling Box methods. The results obtained from the ICI Pilling Box method demonstrated a higher pilling resistance than the pilling grade using the Martindale method for all knitted fabrics. This is because the ICI Pilling Box method was performed at a low mechanical force, while test specimens were dropped randomly on a wooden board during rotations. However, mechanical force is higher in the Martindale tester than in the ICI Pilling Box method because consistent friction is formed by the Lissajous pattern form on the fabric (ISO 12947-1: 1998). In both test methods, knitted fabrics made from finer ring yarns had a higher pilling resistance than fabrics from coarser yarns. The reason for this is that the coarser yarns had less twist and fibres are easily pulled from the yarn cross-section. On the contrary, knitted fabrics from finer yarns had a compact structure, which means fibres would be hidden by twist and are hard to raise by the piler. The researchers Omeroglu and Ulku also reported a similar concept [2].

Table 2: Analysis of variance of knitted properties

Fabric properties		Sum of squares	Df	Mean square	F	Sig.
Pilling (Martindale method)	Between groups	0.333	5	0.167	1.333	0.385
	Within groups	0.375	3	0.125		
Pilling (ICI Box method)	Between groups	0.583	5	0.292	13.500	0.004
	Within groups	0.250	3	0.083		
Abrasion resistance (appearance change)	Between groups	1.083	5	0.542	13.000	0.033
	Within groups	0.125	3	0.042		
Abrasion mass loss (at 5,000 rubs)	Between groups	0.336	5	0.168	0.478	0.660
	Within groups	1.054	3	0.351		
Abrasion mass loss (at 7,500 rubs)	Between groups	4.606	5	2.303	11.589	0.038
	Within groups	4.348	3	1.449		
Abrasion mass loss (at 10,000 rubs)	Between groups	7.293	5	3.646	12.006	0.000
	Within groups	5.454	3	1.818		
Abrasion mass loss (at 15,000 rubs)	Between groups	16.427	5	8.214	8.773	0.010
	Within groups	13.896	3	4.632		
Abrasion mass los (at 20,000 rubs)	Between groups	16.695	5	8.347	11.102	0.008
	Within groups	22.724	3	7.575		
Snagging resistance	Between groups	3.083	5	1.542	18.500	0.021
	Within groups	0.250	3	0.083		

Table 3: Pilling resistance of knitted fabrics

Yarn linear density (tex)	Fabric code	Evaluation methods	
		Martindale method	ICI Pilling Box
21	K1	3/4	4–5
	K2	3	4
25	K3	3	4
	K4	3/4	3–4
30	K5	3	3–4
	K6	2/3	3–4

As is evident from Table 2, the pilling resistance of knitted fabrics in the ICI Pilling Box method resulted in a significant change at an F-value of 13.500 and P-value of 0.004. On the other hand, knitted fabrics did not show a significant difference after the pilling property test using a Martindale Abrasion and Pilling device with an F-value of 1.333 and P-value of 0.385. In previous studies, some researchers reported a similar concept, i.e. pilling tendency increased as mass per unit area of polyester-cotton blended fabrics increased. [35, 36]. As mentioned above, multiple regression results proved that the pilling resistance of knitted fabrics (ICI Pilling Box method) had a negative correlation with studied yarn parameters with an adjusted R^2 value of -0.760.

Effect of yarn parameters on snagging resistance

Snagging resistance was evaluated using ICI photographic snagging standards, which consists of five incremental photo replicas, grades 5 to 1. Grade 5 indicates no snagging, grade 4 indicates slight snagging grade 3 indicates moderate snagging, grade 2 indicates sever snagging and grade 1 indicates very severe snagging. As shown in Figure 3, the snagging resistance of knitted fabrics decreased as yarn linear density (tex) increased and twist decreased. Knitted fabrics K1 and K2 made from 21 and 25 tex had a higher snagging resistance (grade 4–5), followed by fabric from 30 tex. The snagging grade also declined as yarn twist decreased. This is because knitted fabrics from higher twist yarns are very strong and fibres are held firmly in the yarn cross-section, meaning they are not easily snagged by sharp and rough objects. As stated in a previous study, yarn strength generally increases as yarn twist increases (19). However, fabrics made from coarser yarn with a lower twist demonstrated a poor snagging grade because yarns with less yarn twists have low turns per meter in the yarn cross-section, and are more easily snagged by sharp materials. These findings confirm an earlier study by Paek [7].

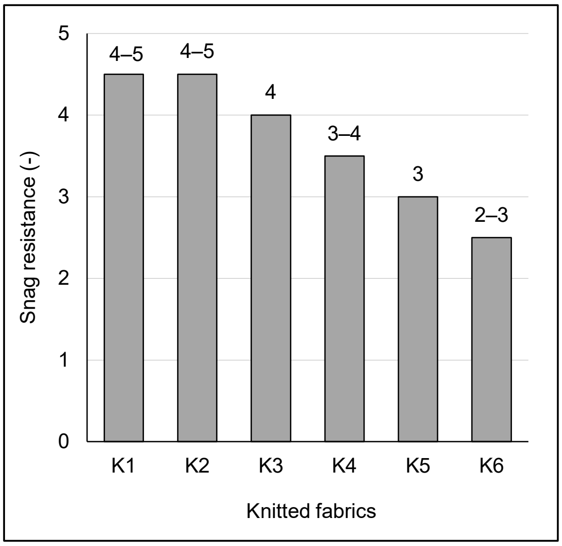

Figure 3: Snagging resistance

As shown in Table 2, the snagging resistance of knitted fabrics was affected by yarn parameters at an F-value of 18.500 and P-value of 0.021. Multiple linear regression proved that yarn parameters had very good correlation with the snagging resistance of fabrics at an adjusted R2 value of 0.949 (94.9%). In addition, yarn count and fabric thickness were highly correlated with the snagging resistance of knitted fabrics at an adjusted R2 value of 0.898 (89.8%) and 0.955 (95.5%), respectively. Textile materials, such as knitted fabrics and military cloths, are subjected to snagging. Rough objects, fingernails or toenails are some initiators of the snagging effect for knitted fabrics. Therefore, knitted fabric manufacturers should consider yarn count and twist for the desired snagging resistance of fabrics.

4 Conclusion

Six 100% cotton single jersey knitted fabrics were produced from 21, 25 and 30 tex ring-spun yarns with different twist levels. The knitted fabrics underwent half-bleach treatment and drying. The abrasion, pilling and snagging properties of knitted fabrics were evaluated using a Martindale Abrasion and Pilling tester, the ICI Pilling Box method and a Mace snagging tester. The results obtained showed that knitted fabric made from a finer count of 21 tex with highest yarn twist of 920 TPM demonstrated the highest mass loss ratio of 2.12–10.76% (poor abrasion resistance 89–97.88%) between 5,000 to 20,000 abrasion cycles. On the contrary, single jersey knitted fabrics made from coarser yarn (30 tex) with the lowest twist (826 TPM) demonstrated a higher abrasion resistance of 96.4–98.9% (mass loss 1–3.5%). The pilling propensity increased as yarn count (tex) increased and twist decreased. Linear regression results revealed that yarn count and twist were highly correlated with abrasion resistance (mass loss method) at an adjusted R^2 value of 98.6% or 0.986 after 20,000 rubs. The snagging resistance of knitted fabrics increased as yarn twist and yarn fineness increased. Generally, abrasion resistance was highly affected by the thickness of the fabric, while regression analysis proved that fabric thickness and mass loss ratio had very high correlation with an adjusted R2 value of 93.8%.

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