WEAR BEHAVIOUR OF SCOURED, DYED AND FINISHED POLYLACTIDE/WOOL AND POLYESTER/WOOL FABRICS

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Summary

Polyester fibres are greatly used in textiles but depend on fossil fuel resources. Poly-(lactic acid) (PLA) is an aliphatic polyester that can be derived from 100% renewable resources. The stress-strain plot of a polylactide fibre seems to be especially compatible with that of wool. Consequently polyester/wool 55/45 and polylactide/wool 55/45 yarns were spun using the Sirospun process and plain and twill woven fabrics were industrially produced. Fabrics were subjected to a conventional finishing process (washing, heat setting, dyeing and finishing with and without anti pilling agent) and the wear behaviour was measured through abrasion tests using a Martindale abrasion tester. Weight loss by abrasion and bursting behaviour of the original non-abraded and abraded fabrics were measured. The effect of dyeing and finishing is especially relevant for PLA/Wool blended fabrics that affect the wear behaviour of them. The effects on PET/Wool blends are not relevant in comparison with those induced on PLA/Wool blends.

Introduction

Polyester fibres cover approximately the 40% of world textile consumption [1]. Like all synthetic polymers, they depend on fossil fuel resources. Poly-(lactic acid) (PLA) is an aliphatic polyester that can be derived from 100% renewable resources [2]. The stress-strain plot of a polylactide fibre seems to be especially compatible with that of a wool fibre [3], consequently blended yarns should give especially relevant properties to manufactured textile fabrics. To this end polyester/wool 55/45 and polylactide/wool 55/45 yarns were spun using the Sirospun process. Plain and twill woven fabrics were produced. Fabrics were subjected to a conventional finishing process (washing, heat setting, dyeing and finishing with and without anti-pilling agent).

Materials and methods

Blended Sirospun yarns 55/45 PLA/Wool and PET/Wool 2×16.7 tex were spun with 640/660 tpm. The most relevant characteristics of the fibres were as follows: PLA fibres especially designed for wool spinning 75 mm in length and 3 dtex in fineness, Polyester fibres (Trevira 340) 2.4 dtex in fineness and Australian wool of 20.5 µm. Yarns were produced at the spinning mill Antero Brancal e Filhos Lda. (Covilhã, Portugal) and fabrics were weaved, dyed and finished at Fitecom Company (Tortosendo-Covilhã, Portugal) using the normal full production conditions.

PLA/Wool fabrics

Plain weave washed and heat set fabrics were made by 24 ends/cm and 22.5 picks/cm resulting in a fabric of 163.8 g/m² and 0.384 mm in thickness. Breaking strength of the fabric according to the NP EN ISO 13934-1 Standard [4] was in warp direction 312.6 N and in weft direction 346.0 N. Tearing strength of the fabric measured according to the NP EN ISO 13937-1 Standard [5] was in warp direction 14.99 N and in weft direction 15.62 N.

Twill weave washed and heat set fabrics were made by 26.5 ends/cm and 28.5 picks/cm resulting in a fabric of 191.5 g/m² and 0.486 mm in thickness. Breaking strength of the fabric measured according to the NP EN ISO 13934-1 Standard [4] was in warp direction 416.9 N and in weft direction 396.1 N. Tearing strength of the fabric measured according to the NP EN ISO 13937-1 Standard [5] was in warp direction 21.09 N and in weft direction 19.10 N.

PET/Wool fabrics

Plain weave washed and heat set fabrics were made by 24 ends/cm and 22.5 picks/cm resulting in a fabric of 159.8 g/m² and 0.378 mm in thickness. Breaking strength of the fabric measured according to the NP EN ISO 13934-1 Standard [4] was in warp direction 555.0 N and in weft direction 577.4 N. Tearing strength of the fabric measured according to the NP EN ISO 13937-1 Standard [5] was in warp direction 20.00 N and in weft direction 21.21 N.

Twill weave washed and heat set fabrics were made by 26.5 ends/cm and 28.5 picks/cm resulting in a fabric of 195.3 g/m² and 0.463 mm in thickness. Breaking strength of the fabric measured according to the NP EN ISO 13934-1 Standard [4] was in warp direction 659.6 N and in weft direction 659.2 N. Tearing strength of the fabric measured according to the NP EN ISO 13937-1 Standard [5] was in warp direction 25.6 N and in weft direction 25.3 N.

Processing of fabrics

All washed and heat set fabrics were subjected to the same procedure of dyeing and finishing according to the conventional procedures applied at Fitecom Company. Some fabrics were finished including an anti pilling agent.

Abrasion trials

Wear behaviour of the fabrics was measured by subjecting the samples to abrasion tests using a Martindale abrasion tester. The abradant fabric was that described at the BS 5690:1979 [6]. Fabrics were subjected to 1, 2, 4, 8 and 12 abrasion kcy under two pressure levels (3 kPa and 9 kPa). The abrasion resistance was measured by the mass loss induced by abrasion (mg) and the mass loss rate (mg/kcy) [7].

Fabric bursting test

Original and abraded fabrics were subjected to a bursting strength test, using a device the dimensions of which enabled us to test the cut disk samples 39.5 mm in diameter of the fabrics used at the Martindale Wear and Abrasion tester. A cylindrical probe made of steel with hemispherical head of diameter 9±0.1 mm was pressed against the fabric disk up to breakage in a MT-LQ dynamometer of Stable Micro Systems. The hemispherical head radius is of 20 mm. The probe was pressed against the fabric at a speed of 0.2 mm/s. Load and extension values recorded during the test enabled us to calculate the bursting load (N), bursting deformation (mm) and bursting energy (mJ) up to breakage.

Results and discussion

The abrasion and bursting tests were made on the four specimens subjected to abrasion at the Martindale tester. Four original non-abraded specimens were also burst at the MT-LQ dynamometer to measure the initial values of bursting strength, deformation and energy for comparison purposes. Results are shown in Table 1.

There is a relevant effect of the composition on the properties of the original fabrics. It is highly relevant that Polyester yields higher bursting strength and energy than PLA to the fabrics. Regardless the composition it is evident the decrease induced by dyeing and dyeing including the anti pilling KD agent on both properties.

As regards the bursting deformation, the effect of composition is not as relevant as in strength and energy, although the bursting deformation of PLA/Wool fabrics is lower than that of the PET/Wool fabrics. The anti pilling agent made of polymers, avoids the emergence of fibres out of the fabrics when abraded, and makes the bursting deformation of fabrics to ascend being higher than that of the non-treated ones.

Table 1: Bursting strength, deformation and energy (mean of four specimens ± confidence interval at 95%) of the original non abraded 55/45 PLA/Wool and PET/Wool fabrics according to the weave and treatment (washed and heat set, dyed and dyed including the anti pilling agent KD).

Bursting	Strength [N]		Deformation [mm]		Energy [mJ]	
Weave	Plain	Twill	Plain	Twill	Plain	Twill
PLA/Wool Fabrics:						
Washed&HS	102.32±3.38	142.99±3.38	6.89±0.12	7.07±0.12	336.30±23.37	452.38±23.37
Dyed	-	86.42±3.38	-	5.21±0.12	-	206.87±23.37
Dyed+KD	66.15±3.38	79.22±3.38	5.56±0.12	5.85±0.12	165.82±23.37	207.83±23.37
PET/Wool Fabrics:						
Washed&HS	291.65±10.91	355.80±10.91	9.83±0.27	10.38±0.27	1186.63±55.65	1514.12±55.65
Dyed	251.23±10.91	292.95±10.91	8.25±0.27	8.60±0.27	879.82±55.65	1058.11±55.65
Dyed+KD	231.74±10.91	291.80±10.91	8.85±0.27	8.81±0.27	914.93±55.65	1095.42±55.65

Figure 1 a) shows the relevant differences between PET/Wool and PLA/Wool fabrics in bursting strength being the former three times higher than the latter. After dyeing, bursting strength decreases specially in PLA/Wool blend. Although twill weave lead to more resistant fabrics, the decrease in bursting strength after dyeing is more pronounced in twill weave than in the plain one. The effect of the anti pilling agent slightly increases bursting strength especially in plain weave probably due to the shorter free length of yarns between two consecutive interlacing points in this weave pattern.

Figure 1 b) shows the short differences in bursting deformation between PET/Wool and PLA/Wool fabrics, although the greater values of the former. Twill weaves lead to a higher bursting deformation than plain weave. After dyeing, the bursting deformation decreases, although the application of the anti pilling agent favours an increase in bursting deformation especially in PLA/Wool blend.

Figure 1 c) shows the evolution of bursting energy according to composition, treatment and weave. PET/Wool fabrics show higher values of bursting energy than those of PLA/Wool fabrics. Dyeing decreases bursting energy although the application of an anti pilling agent favours the bursting energy of the fabrics.

Mass loss caused by abrasion

Table 2 shows the mean values of the fabric mass abraded at the Martindale tester after 1, 2, 4, 8 and 12 kcy of abrasion under 3 and 9 kPa pressure. PLA/Wool (Fig. 2a) and PET/Wool (Fig. 2b) fabrics are grouped according to their weave and treatment applied.

The application of the Analysis of Variance enabled us to identify the influence of abrasion pressure and cycles, weave and treatment on the mass loss caused by abrasion on the fabrics. As regards de washed and heat set PLA/Wool fabrics the most significant effect was that of the abrasion pressure causing mean losses of 6.49 mg when abraded under 3 kPa and 25.34 mg when abraded under 9 kPa. The higher the abrasion cycles the greater the mass abraded increasing from 6.35 to 31.13 mg when abrasion cycles ascend from 1 to 12 kcy. No differences between weaves are observed.

The abrasion pressure is also the most significant effect on mass loss of the dyed fabrics: mean losses of 9.19 and 29.52 mg are induced when abraded under 3 and 9 kPa respectively. The effect of abrasion cycles is stronger on the mass loss of dyed fabrics: it grows from 6.63 to 38.96 mg when abrasion cycles ascend from 1 to 12 kcy. The weave does not influence the amount of abraded mass of dyed fabrics.

When the dyed fabrics treated with anti pilling agent are considered, the most significant effects are pressure and abrasion cycles. The interaction between pressure and abrasion cycles is also significant: the abraded mass increases from 8.00 to 27.72 (more than 3 times) when abrasion cycles ascends from 1 to 12 kcy under 3 kPa, while an increase from 16.83 to 89.21 mg (more than 5 times) is observed under 9 kPa. No effect of the weave appears.

Table 2: Mass loss of fabrics [mg] caused by abrasion at the Martindale Abrasion tester, according to fabric composition, weave, treatment, abrasion pressure against standard abradant (BS 5690:1979) and abrasion kcy.

	Abrasion	55/45 PLA/Wool fabric				55/45 PET/Wool fabric			
	Pressure	3 kPa		9 kPa		3 kPa		9 kPa	
	& kcy	Plain	Twill	Plain	Twill	Plain	Twill	Plain	Twill
Washed & Heat Set	1	4,79	3,56	11,43	5,60	0,04	0,03	0,00	0,68
	2	6,43	4,31	13,02	9,24	0,32	0,22	0,18	0,87
	4	7,82	5,32	17,74	16,32	1,00	0,26	0,57	2,99
	8	8,43	6,98	22,98	49,88	1,08	1,08	5,14	3,32
	12	9,82	7,43	34,05	73,20	1,64	1,22	13,86	3,34
Dyed	1	-	4,02	-	7,07	0,67	0,87	0,90	2,19
	2	-	5,21	-	11,15	0,97	1,49	2,22	3,57
	4	-	7,80	-	16,71	1,66	1,94	2,72	5,21
	8	-	9,83	-	30,08	2,18	2,81	4,43	10,11
	12	-	11,36	-	69,69	2,65	3,80	4,82	15,76
Dyed+KD anti pilling	1	9,05	6,95	22,44	11,21	0,84	0,87	1,49	1,99
	2	12,09	9,38	33,12	19,40	1,38	1,18	2,17	3,71
	4	19,01	13,74	47,23	27,93	1,74	1,73	2,88	4,77
	8	22,79	16,78	69,56	37,38	2,20	1,99	4,35	8,81
	12	30,93	24,50	78,41	100,0	2,99	2,42	5,24	13,71

As regards the washed PET/Wool fabrics, a slight effect of abrasion cycles is observed on the abraded mass that grows from 0.19 to 5.02 mg when cycles ascend from 1 to 12 kcy. Neither the abrasion pressure nor the fabric weave significantly affect the mass loss of the fabrics.

When dyed fabrics are considered, the abraded mass is significantly influenced by the abrasion cycles and pressure and by the weave. The mean loss of mass induced by abrasion grows from 1.16 to 6.76 mg when cycles ascend from 1 to 12 kcy. When abrasion pressure changes from 3 to 9 kPa the mean mass loss grows from 1.90 to 5.19 mg. The influence of weave interacts with the abrasion pressure: the mass loss for plain weave abraded under 3 and 9 kPa grows from 1.63 to 3.02 mg (near 2 times), while for twill weave the increase is from 2.18 to 7.37 (more than 3 times). Twill weaves show higher mass loss under abrasion (4.78 mg) than plain weaves (2.32 mg).

When the dyed fabrics treated with anti pilling agent are considered, the factors affecting the mass loss are similar to those observed in dyed fabrics. The mean loss of mass induced by abrasion grows less than for dyed fabrics, from 1.30 to 6.09 mg when abrasion cycles ascend from 1 to 12 kcy. When abrasion pressure increases from 3 to 9 kPa the mean values of mass loss are lower than those observed in dyed fabrics, from 1.73 to 4.91 mg. The influence of weave interacts with the abrasion pressure: the mass loss for plain weave when is abraded under 3 kPa and 9 kPa respectively grows from 1.83 to 3.23 mg (near 2 times), while for twill weave the increase is from 1.64 to 6.60 (4 times). Twill weaves show higher mass loss under abrasion (4.12 mg) than plain weaves (2.53 mg).

Bursting behaviour, weight loss and abrasion test

Figures 3 and 4 show the results of bursting strength, deformation and energy of the abraded fabrics compared with those of the original non abraded ones for PLA/Wool and PET/Wool respectively. Variations are given in percentage. If abrasion does not affect fabric structure, it can be expected that variations in bursting behaviour should be directly related with the abraded mass of the fabric. The higher the abraded mass the shorter the bursting property of the fabric. If the influence of abrasion depends on the weave and modifies fabric structure, test conditions and fabric weave will play a significant role on the variation of bursting properties, otherwise the abraded mass should be the unique variable explaining variations in bursting property. To this end, a multiple regression analysis relating the variations in bursting strength BS (%), deformation BD (%) and energy BE (%) with abraded mass AM (mg), fabric weave FW (1 for plain and 2 for twill), abrasion pressure AP (3 and 9 kPa) and abrasion cycles AC (1, 2, 4, 8 and 12 kcy) has been performed. The interaction terms FW×AP and AP×AC have been included in the model. To get the optimal equation the forward regression procedure including significant terms has been applied [8]. Table 3 shows the "best" regression equations to predict the effect of abrasion on the characteristics of the non-abraded fabrics according to fabric composition and treatment. The contributions of each variable to the total determination coefficient R^2 are also included.

Table 3: Multiple regression analysis of the variations in bursting strength BS, deformation BD and energy BE vs. original non abraded fabrics, in function of abraded mass AM, fabric weave FW, abrasion pressure AP, abrasion cycles AC and interactions according to fabric composition (PLA/Wool, PET/Wool) and treatments (washed and heat set WHS, dyed D and dyed including anti pilling agent D+KD).

		Contributions to the determination coefficient R^2						
	Best predictive equation	AM	FW	AP	AC	FW×AP	AP×AC	Total
Variations in bursting strength (%) PLA/Wool fabrics:								
BS_{WHS}	123.92-1.53AM-11.79FW	89.64	4.73	-	-	-	-	94.37
BS_{D}	110.87-1.25AM-4.11FW+0.76AP	97.38	0.83	0.79	-	-	-	99.00
BS_{D+KD}	117.17-1.16AM	89.03	-	-	-	-	-	89.03
Variations in bursting strength (%) PET/Wool fabrics:								
BS_{WHS}	97.53-7.29AM+0.87AC	94.63	-	-	1.91	-	-	96.54
BS_{D}	87.82-1.49AM+9.73FW-0.17AP×AC	5.24	8.09	-	-	-	78.62	91.95
BS_{D+KD}	152.65-2.64AM-23.93FW-6.38AP+3.16FW×AP	60.89	5.34	13.64	-	12.30	-	92.17
Variations in bursting deformation (%) PLA/Wool fabrics:								
BD_{WHS}	111.05-0.67AM-0.80FW×AP	80.34	-	-	-	5.63	-	85.97
BD_{D}	117.83-0.42AM-4.40FW	74.03	6.85	-	-	-	-	80.88
BD_{D+KD}	146.06-0.96AM-15.2FW	64.10	7.22	-	-	-	-	71.32
Variations in bursting deformation (%) PET/Wool fabrics:								
BD_{WHS}	105.38-4.53AM	88.33	-	-	-	-	-	88.33
BD_{D}	99.98+1.3AC+0.42FW×AP-0.31AP×AC	-	-	-	12.9	8.69	57.45	79.04
BD_{D+KD}	99.35+0.48FW×AP-0.2 AP×AC	-	-	-	-	12.24	57.16	69.40
Variations in bursting energy (%) PLA/Wool fabrics:								
BE_{WHS}	60.76-1.3AM+32.16FW+9.01AP-6.75FW×AP	83.03	5.94	2.60	-	4.67	-	96.24
BE_{D}	117.81-1.28AM-5.97FW	95.57	1.71	-	-	-	-	97.28
BE_{D+KD}	109.67-0.93AP×AC	-	-	-	-	-	88.79	88.79
Variations in bursting energy (%) PET/Wool fabrics:								
BE_{WHS}	143.87-6.63AM-20.25WF-7.41AP+3.66FW×AP	89.23	3.35	4.03	-	1.57	-	98.18
BE_{D}	89.86+8.56FW+1.53AC-0.57 AP×AC	-	7.60	-	6.57	-	74.05	88.22
BE_{D+KD}	102.86-0.36 AP×AC	-	-	-	-	-	76.98	76.98

Focussing the results on bursting strength there is a stronger relationship with abraded mass in PLA/Wool fabrics than in PET/Wool ones. Washed and heat set fabrics account for the highest contribution of the abraded mass on the variation of bursting strength. PET/Wool dyed and treated with anti pilling agent show a high contribution of the weave and abrasion conditions on bursting strength. The abrasion in PLA/Wool blends directly affects the bursting behaviour, while the higher resistance to abrasion of PET/Wool fabrics facilitates the other parameters to play a significant role on bursting behaviour. The same occurs when bursting deformation and energy are considered. Heat wet treatment of dyeing helps the polyester fibre to stabilise its structure while the low resistance of PLA to hydrolysis marks differences between the more stable dyed PET fabrics than less stable of PLA is included.

Influence of the anti pilling treatment on bursting behaviour of abraded fabrics

The application of the analysis of variance to compare the results of dyed fabrics with those dyed including an anti pilling agent enabled us to see the effect of this treatment of

PET/Wool blends. Treated fabrics show higher bursting strength (98.14 vs. 91.79%) and lower bursting deformation (97.12 vs. 100.88%). As regards the PLA/Wool blend the fabrics treated with the anti pilling agent although show higher abraded mass (30.6 vs. 19.4 mg) the bursting deformation was slightly reduced (103.0 vs. 93.9 %).

Conclusions

In the light of the results obtained on PLA/Wool and PET/Wool blends washed and heat set, dyed and finished with and without anti-pilling agent, tested for bursting behaviour before and after being subjected to abrasion, the following conclusions can be drawn:

Non-abraded fabrics

Polyester component in the blend yields to higher bursting strength and energy than polylactide. The decrease in these properties after dyeing is especially relevant when polylactide are present in the blend.

Twill weave leads to more resistant fabrics than plain weave. After dyeing, the decrease in bursting strength is more pronounced in twill weave than in plain one. The anti-pilling agent makes the bursting deformation to ascend and slightly increases bursting strength especially in plain weave.

Abraded fabrics

The abrasion pressure greatly affects abrasion resistance of PLA/Wool fabrics regardless its weave. The influence of abrasion cycles is especially relevant on dyed fabrics.

Neither the abrasion pressure nor the abrasion cycles affect the abrasion resistance of the PET/Wool washed and heat set fabrics. When, dyed the abrasion resistance depends on the weave and pressure and abrasion cycles. Twill weaves are less resistant than plain weaves.

Bursting behaviour are strongly related with abraded mass in PLA/Wool fabrics and in PET/Wool ones. The washed and heat set fabrics account for the highest contribution to the abraded mass on bursting strength. The higher abrasion resistance of the PET/Wool fabrics facilitates that besides abraded mass, weave, abrasion pressure and resistance and their interactions play a significant role on bursting behaviour.

The anti pilling agent decreases the bursting deformation of the abraded fabrics, increases the bursting resistance of the PET/Wool fabric and decreases the bursting resistance of the PLA/Wool one.

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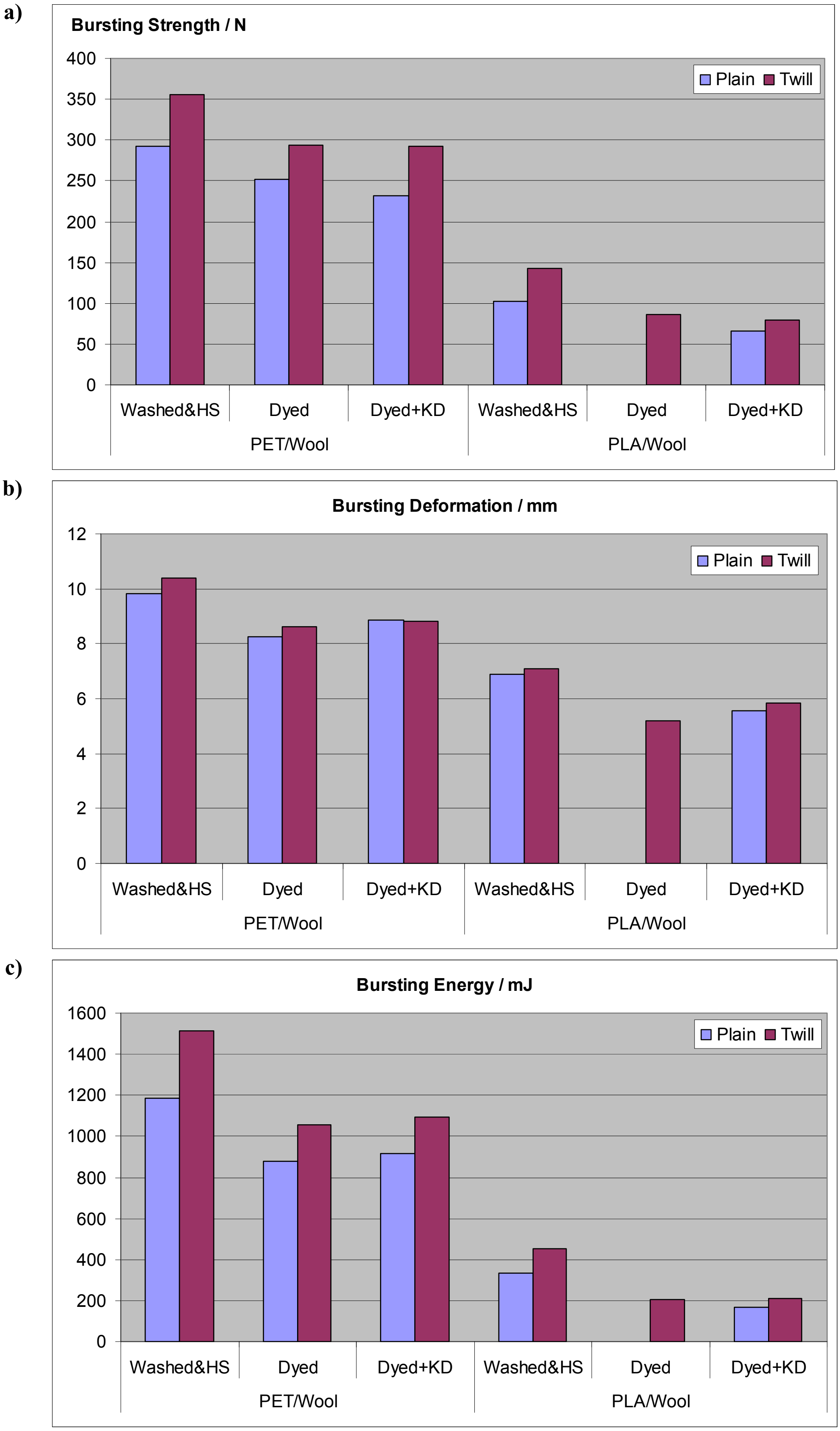


Figure 1: Bursting strength, deformation and energy of the original PET/Wool and PLA/Wool washed and heat set fabrics, dyed fabrics and dyed including an anti pilling agent (KD).

a)

b)

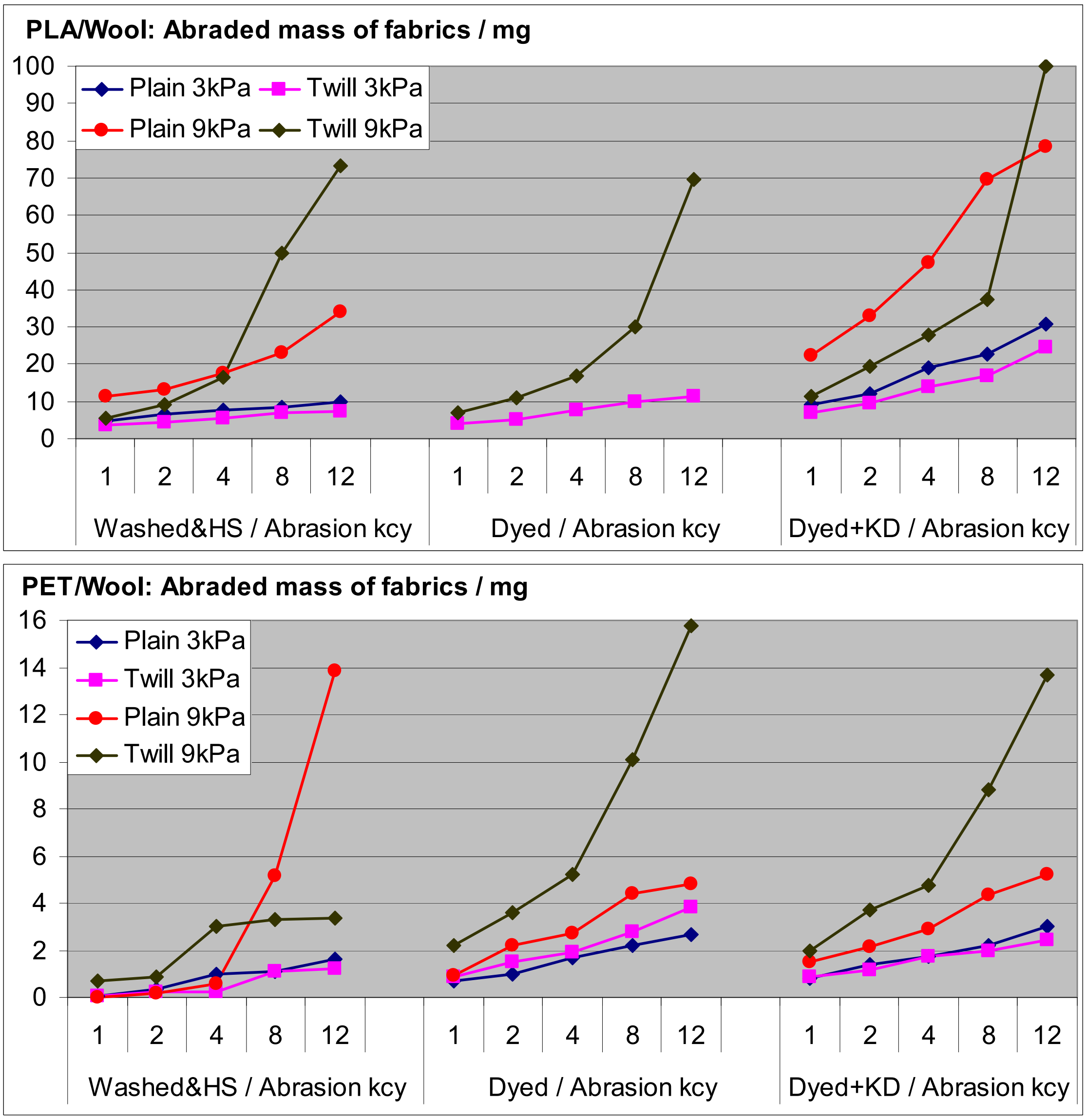


Figure 2: Abraded mass of PLA/Wool (a) and PET/Wool (b) plain and twill fabrics, washed and heat set, dyed and dyed with anti pilling agent and abraded under two different pressures (3 and 9 kPa) from 1 to 12 kcy using a Martindale abrasion tester.

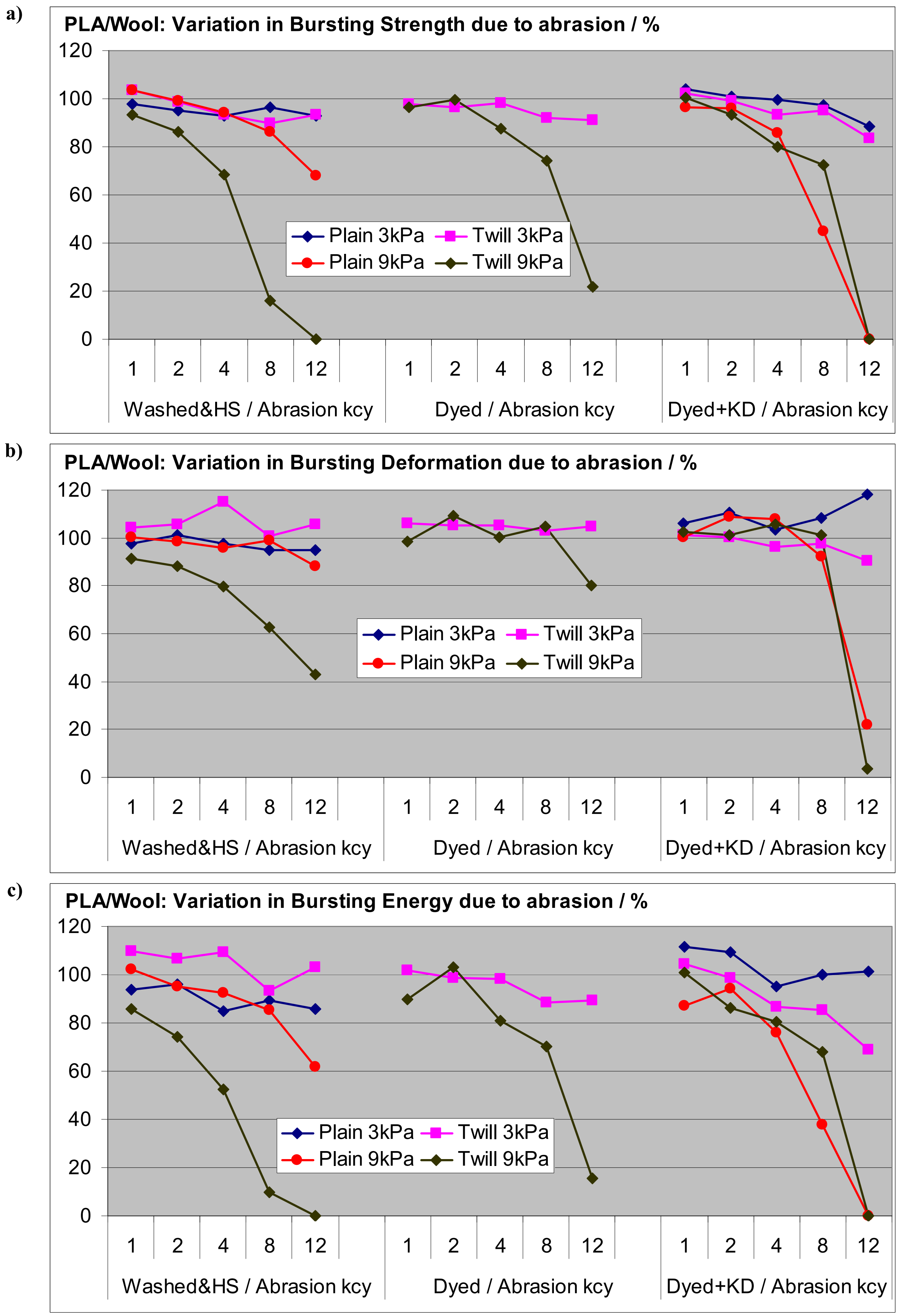
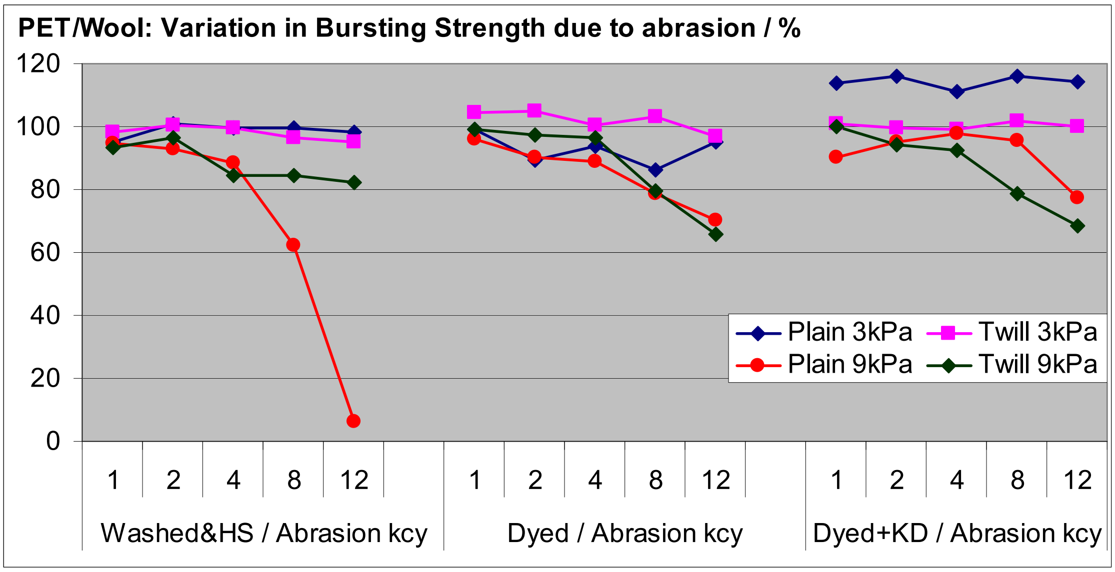


Figure 3: PLA/Wool fabrics. Variation in Bursting Strength (a), Deformation (b) and Energy (c) induced by abrasion in function of the weave, treatment (washing and heat setting, dyeing and dyeing including anti pilling agent), abrasion pressure and number of abrasion cycles in a Martindale abrasion tester.

a)



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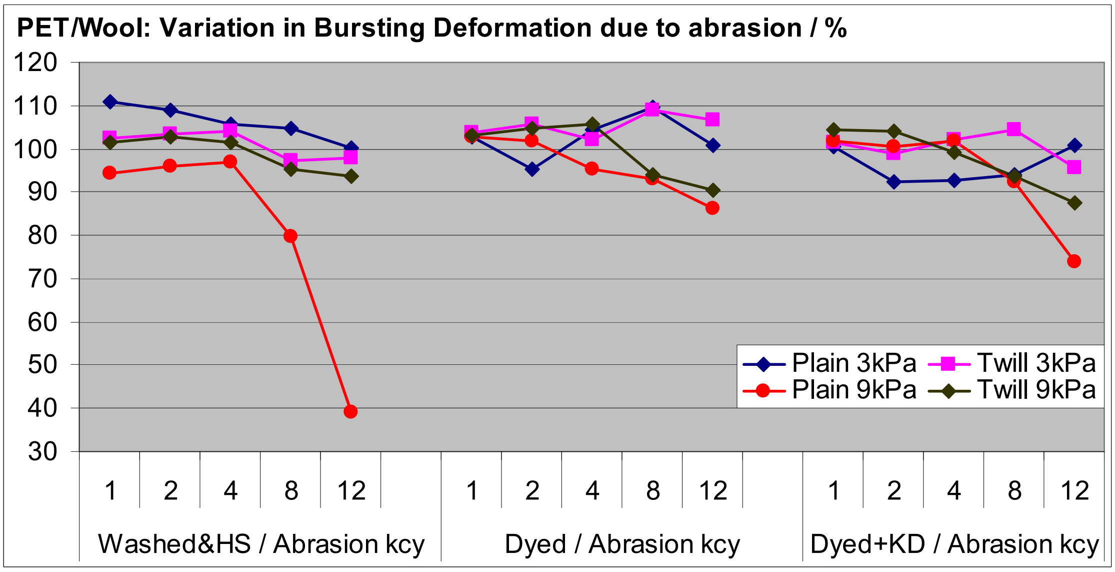

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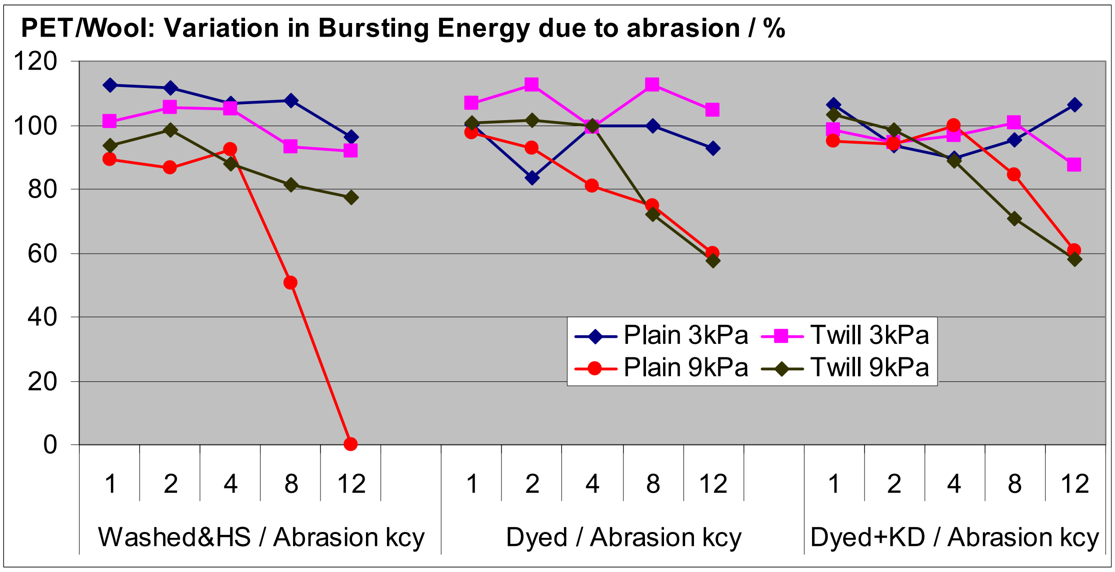

Figure 4: PET/Wool fabrics. Variation in Bursting Strength (a), Deformation (b) and Energy (c) induced by abrasion in function of the weave, treatment (washing and heat setting, dyeing and dyeing including anti pilling agent), abrasion pressure and number of abrasion cycles in a Martindale abrasion tester.