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Performance Properties of Plain Knitted Fabrics Made from Open End Recycled Acrylic Yarn with the Effects of Covered and PBT Elastic Yarns

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Abstract: In this research, the performance properties of plain knitted fabrics made from open end recycled and virgin acrylic yarns are comparatively investigated, together with the effects of added covered and PBT elastic yarns. The previous studies about the recycling of textile wastes and their usage were mainly focussed on waste type including cotton fibre. Although acrylic textile wastes constitute one of the most common recycled waste types after cotton wastes, there have been no studies on the usage of this type of waste as a fabric form in the literature. The recycled acrylic yarn is spun from 100 % acrylic fibre wastes subjected to mechanical recycling process of garneting. Covered and PBT elastic yarns are incorporated to give an added value to the recycled acrylic fabrics. The experimental and statistical results reveal that the fibre type (acrylic waste fibre and virgin acrylic fibre) and the elastic yarn state (addition and type) parameters affect all the performance properties of the fabrics significantly. The recycled acrylic fabrics exhibit higher thickness, pilling tendency, abrasion resistance and coursewise extension results and lower bursting strength results than the corresponding virgin acrylic fabrics. As far as the elastic yarn state is considered, it is observed that the fabrics with the covered yarn reveal the highest stitch density, mass, thickness and walewise extension results, followed by the fabrics with the PBT yarn. The highest bursting strength and the lowest pilling tendency results are obtained for the fabrics with the PBT yarn. Addition of the elastic yarn improves the abrasion resistance of the recycled and virgin acrylic fabrics. No statistically significant difference is found between the abrasion results of the recycled acrylic fabrics with the covered yarn and the PBT yarn.

Keywords: Acrylic fibre waste, Elastane, Covered yarn, PBT yarn, Fabric performance

Introduction

Textile industry is one of the largest industries that consume enormous amounts of raw materials, water, energy and chemicals and release harmful pollutants such as gases, chemicals and pesticides into air, water and soil. All of these factors are the major contributor to environmental pollution and consumption of scarce natural resources. The total global fibre production, which closely reflects the consumption of textile products was approximately 111 million tons in 2018 [1]. According to increasing fibre production rates per year, it is estimated to reach approximately 130 million tons in 2025 [2]. Growing increases in the production and consumption of textile and apparel products make eco-friendly and sustainable production necessary. One of the most important steps in sustainable production is recycling. The production of textiles and apparel products generates a considerable amount of solid textile wastes, which also cause many environmental problems during disposal of them such as landfill occupation, contamination and global warming. Recycling of solid textile wastes provides valuable fibre source for textile manufacturers as alternative to virgin fibres and eliminates the adverse environmental effects associated with the production of virgin fibres and textile products.

The simplest and cheapest method for the recycling of textile wastes is to use mechanical recycling method. In this method, textile wastes are mechanically broken down into individual fibres. This is carried out on mechanical fibre opening machines known under the name of shredding or garnet machines, each of which has one or more rotating drums covered with sharp steel pins or wires [3]. The obtained recycled fibres are widely spun into yarns for knitting and weaving. Before fibre opening process, classification of textile wastes is required to obtain recycled fibres having certain properties. Classification is especially done according to colour, raw material content, source, etc. On the raw material content basis, textile wastes are usually classified as cotton, acrylic and wool containing wastes. It is well known that acrylic fibre, which is composed of at least 85 % by weight of acrylonitrile units, is one of the synthetic fibres. Synthetic fibres (including polyester, acrylic, nylon and polypropylene) account for about 60 % of global textile production [2,4]. Acrylic fibre constitutes 5 % of the total synthetic fibre production and with this rate it ranks the fourth among the synthetic fibres [5]. Acrylic fibre resembles wool in terms of bulkiness, warmth, handle and appearance [6]. Thus, it is widely used as a low cost alternative to wool especially in knitted sweaters, socks, blankets, carpets, etc. The other prominent properties are excellent resistance to sun light, microorganism and chemicals, ease of care, reasonably durable and ease of dyeing to heavy depths [6]. In spite of not being produced as much as other synthetic fibres, acrylic fibre still occupies an important place in apparel, home furnishing and industrial applications due to having some specific advantageous properties. Since acrylic fibre is widely found in certain application areas, high quantities of acrylic containing textile wastes emerge

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during the production of the products made from it. Textile wastes containing acrylic fibre constitute one of the most recycled textile waste types after textile waste type containing cotton. Acrylic textile wastes are brought into fibre form by garnet type fibre opening machines. Recycling process highly gives damage to fibres, causing a high level of fibre breakages. After recycling process, obtained fibres may include fibres in short and variable lengths and improperly opened yarn or fabric pieces. The negative properties of recycled fibres decrease the yarn quality and limit the yarn count. To compensate for low quality properties, recycled fibres need to be blended with virgin fibres. The recycled acrylic yarns are used in relatively low quality products with limited applications such as upholstery, carpet, and rug. To be able to use recycled acrylic yarns in wide range of high added value apparel applications such as knitted sweaters and cardigans, more research and development about the production of recycled acrylic fabrics with better quality, functional properties and aesthetic appearance are necessary.

Elastic fibres, which are known for high degree of stretch and recovery are commonly used to enhance some of the performance and comfort properties of fabrics by providing freedom of movement, shape retention, compact surface, thickness, texture, aesthetic appearance, etc. [7]. Elastic fibres are obtained by spinning polymers of specific molecular structure or modified polymers [8]. According to polymer materials, many different types of elastic fibres are commercially available. Among elastic fibres, traditional spandex or lycra constitutes the most widely used elastic fibre type. Spandex, which contains 85 % or more mass of segmented polyurethane possesses an elongation at break more than 200 %, usually 400-800 % even under low loads and up to 99 % elastic recovery [8,9]. Spandex can be used in combination with another effect yarns as well as used alone. Covered yarn, which is a kind of compound yarn has a core that is completely covered by fibre or another yarn. In the case of elastic covered yarn, the core consists of an elastic yarn such as spandex and lycra and the other effect yarn might be filament yarn such as polyester or nylon [10].

PBT fibre is a polyester based elastic fibre. As in the case of spandex, PBT has high extensibility and quick recovery properties. The elongation of PBT changes between 24 % and 29 %, which is much lower than the elongation of spandex fibre. In this respect, PBT gives more comfort than spandex [8] because when compared to fabrics with spandex fibre, fabrics with PBT exert less pressure on the body. In addition to good elastic properties, fabrics with PBT fibre have soft and bulkier handle, better dyeing properties, good colour fastness, good dimensional stability, good solvent resistance, high heat resistance and high strength [8,11].

There have been many studies related to the performance properties of the fabrics made from mechanically recycled textile wastes in the literature. Necef *et al.* [12] carried out a study about usability of fabric scraps having cotton into garment manufacture. By using 50/50 % recycled cotton/virgin polyester blend, open end yarn, knitted fabric and garment were produced and then some physical properties of them were compared with those of the products made from 50/50 % virgin cotton/polyester blend. It was reported that there was not any appreciable difference between the qualities of recycled and virgin garments and the garments made from recycled fabric scraps could be used in garment manufacturing. In the next studies [13,14], the physical and thermal performance properties of the socks produced from the 50/50 % recycled cotton/virgin polyester yarn were investigated in comparison with those of the equivalent socks produced from 100 % virgin cotton yarn by considering added elastane effect as well. It was reported that elastane addition and fibre type affected all the performance properties of the socks significantly. It was also stated that when blended with virgin polyester fibre, recycled cotton fibres could be used in the production of socks in acceptable quality. In another research, Yuksekkaya *et al.* [15] performed comparative study on the performance properties of the knitted fabrics constructed from both recycled and virgin cotton and polyester fibres and their 50/50 % blends of these fibres with each other. The fabrics with virgin fibres displayed better performance properties than those with recycled fibres. The studies on woven fabrics produced from recycled cotton fibres were mainly concentrated on denim fabrics and their mechanical properties [16-19].

A literature review on the performance properties of fabrics having textile wastes revealed that researchers were mainly focussed on waste type containing cotton fibres as waste material type. In those previous studies, mechanically recycled cotton fibres were combined with virgin cotton and polyester fibres to be able to improve product quality. However, as can be observed from the literature, use of virgin fibres as blending component in yarn production does not completely fulfil required performance characteristics in the resulting products. Mostly, to reach certain quality, high percentages of virgin fibres are needed, which reduces the amount of recycled fibres used. Combination of recycled yarn with elastic yarn is another promising approach for possibility of acquiring high-value fabrics with new functional and performance properties.

Recycled acrylic fibres obtained from textile wastes containing acrylic fibres are commercially used in open end spinning for knitted and weaving fabric production. However, as far as we know, there have been no published studies on the performance properties of knitted fabrics produced from acrylic textile wastes in the literature. It is thought that utilization of acrylic textile wastes is important to encourage manufacturers to use this waste type in their products.

In the light of the information given above, this study concentrates on the utilization of acrylic fibre wastes in higher quality knitwear products. Due to its wool like properties, acrylic fibre waste is highly suitable for knitwear applications such as cardigans, pullovers and sweaters. The objective of this proposed study is to investigate the performance properties of plain knitted fabrics made from 100 % recycled acrylic open end yarn in comparison with those of virgin acrylic counterparts by taking into the effects of added covered and PBT yarns. Elastic yarns are proposed to improve the quality and performance properties of knitted fabrics and to give an added value to these recycled acrylic fabrics. With added elastic yarns, it is thought that the effect of elastic fibres on fabric structural properties may implicitly cover up low quality properties of the recycled acrylic fabrics. Bearing in mind the positive impacts of recycling on environmental protection and ecological sustainability, an attempt was made to fill existing research gap via producing eco-friendly, low cost and high quality acrylic based sweater like knitted fabrics and presenting the investigated results on the fabric performance properties.

Experimental

For the study, plain knitted fabrics were produced for the knitted garment application area such as sweater, jumper, cardigan and waistcoat. Three different groups of recycled and virgin acrylic plain knitted fabrics having three different elastic yarn states with no elastic yarn, with covered elastic yarn and with PBT elastic yarn were produced by using recycled and virgin acrylic open end yarns in Nm 14 yarn count. The recycled acrylic yarn was made from the highest quality acrylic tops wastes and acrylic fibre wastes from production processes. The waste material type is to great extent responsible for product quality. The best quality is obtained from acrylic fibre wastes because this waste type is quite clean, have pure sorted acrylic fibres and does not require severe fibre opening processes due to being fibre form. The problem with the acrylic fibre wastes is that they might include acrylic fibres in different physical properties since acrylic fibre wastes are collected from different production processes and sources. Before the yarn production process, to open entangled fibres and to bring fibres parallel form, the fibre wastes were subjected to mechanical recycling process of garneting. Therefore, another problem with the acrylic fibre wastes is that the garneting process applied to the wastes may give damage to the fibres.

Due to high fibre quality, acrylic fibre wastes have potential to be used in open end yarn production by 100 % ratio. Thus, for the production of the recycled yarn, acrylic fibre wastes were used as 100 % ratio without using any virgin fibre. The SEM image of acrylic fibre waste type is illustrated in Figure 1. The fibre diameter of the acrylic fibre wastes was measured as 15.64±3.20 micron by following the standard TS EN ISO 137. Average fibre length and fibre length distribution of the acrylic fibre wastes were determined by manually measuring single fibre lengths in accordance with the standard TS 1140. 200 fibre lengths were measured. The fibre lengths were ranged from 10 mm to 75 mm and the average fibre length was measured as 39.53±35.43. Fibre lengths revealed high variation. In order to characterize the fibre length distribution of the acrylic fibre wastes, the histogram of fibre length was also obtained as given in Figure 2. The equivalent virgin acrylic yarn was selected for comparison purpose. Virgin acrylic yarn was produced from 1.3 dtex 38 mm virgin acrylic fibre. The physical characteristics of two types of the yarns are presented in Table 1.

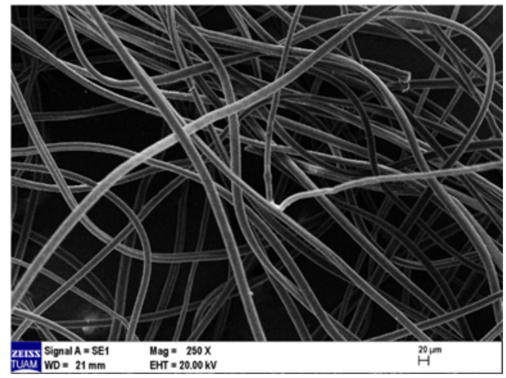

Figure 1. SEM image of the acrylic fibre wastes.

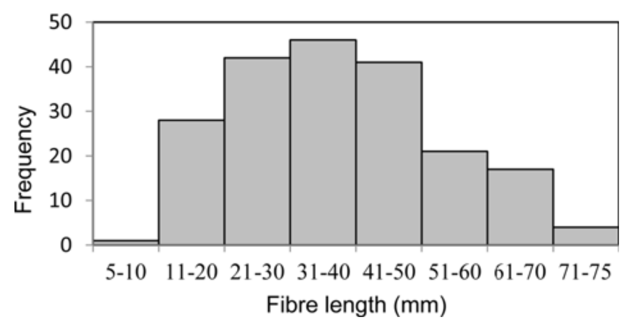

Figure 2. Histogram of fibre length of the acrylic fibre wastes.

Table 1. Physical properties of recycled and acrylic yarns

Properties	Recycled yarn	Acrylic yarn
Count (Ne)	7.20	8.02
Twist (T/m)	384.6	340.00
Tenacity (Rkm)	8.46	18.91
Elongation (%)	18.85	28.73
CVm (%)	13.06	7.90
Thin places (-50 %)	0	0
Thick places (+50 %)	53.5	0
Neps (+280 %)	52.0	0
Hairiness index	9.61	8.10

Table 2. Measured stitch length values of the fabrics

Fabric types			Stitch length (cm)
No elastic yarn	Tight	Recycled	0.728
		Acrylic	0.756
	Loose	Recycled	0.822
		Acrylic	0.825
Covered yarn	Tight	Recycled	0.714
		Acrylic	0.726
	Loose	Recycled	0.772
		Acrylic	0.802
PBT yarn	Tight	Recycled	0.693
		Acrylic	0.704
	Loose	Recycled	0.801
		Acrylic	0.792

In order to improve the performance of the recycled acrylic fabrics, two types of covered and PBT elastic yarns were also added into the fabrics. A covered yarn consists of 50/20 denier textured polyester/lycra yarns. To obtain the same yarn count with the covered yarn, two PBT yarns of 50 and 20 denier counts were used together. The recycled and virgin acrylic yarns were twisted together with the covered and PBT elastic yarns with the twist level of 250 (S) T/m. In addition to two recycled and virgin acrylic yarns, another four types of elastic yarns were obtained by combining two recycled and virgin acrylic yarn types together with two covered and PBT elastic yarns. The six types of yarns are recycled acrylic yarn, virgin acrylic yarn, recycled acrylic/covered yarn, virgin acrylic/covered yarn, recycled acrylic/PBT yarn and virgin acrylic/PBT yarn.

The plain knitted fabrics were knitted on E12 gauge Shima Seiki SVR 122 flat knitting machine under the same machine sets. The number of needles was 400. Each fabric type involving different materials was produced in short and long stitch lengths in order to represent tight and loose knitted structures. Stitch length was determined by measuring unravelled yarn length over 50 wales in the same course by means of HATRA like course length tester. Before measurement, unravelled yarn length was tensioned by hanging a 10 g load. The measured stitch length values are given in Table 2. A total of 12 plain knitted fabrics were prepared for this study from six types of yarns listed above and two levels of fabric tightness.

After knitting, in order to ensure that the fabrics reach their stable state, dry and full relaxation procedures were applied. For dry relaxation, the fabrics were allowed to remain on a flat surface in a standard atmosphere with temperature of 20±2 ºC and relative humidity of 65±2 % for seven days. For full relaxation, the fabrics were washed in a fully automatic washing machine at 40 ºC for one hour and then tumble dried at 70 ºC for one hour. Both of the relaxation treatments were repeated one time. Prior to the tests, all the fabrics were allowed to condition in a standard atmosphere for 24 hours. The wale and course densities (wales/cm and courses/cm) were measured according to TS EN ISO 14971. Then, the product of the wale and course densities were used to obtain the stitch density (stitches per cm^2). The other fabric performance tests were carried out in accordance with the relevant standards, i.e., mass per unit area, TS 251; thickness, TS 7128 EN ISO 5084; bursting strength, TS EN ISO 12947-3; abrasion, TS EN ISO 13938-1; pilling, TS EN ISO 12945-2; extension, TS EN 14704-1.

Surface morphologies of the acrylic fibre waste type and all the yarn and fabric types having different material types were observed with ZEISS LEO 1430 VP model scanning electron microscope (SEM) at magnifications of 250x, 50x and 35x, respectively. SEM analysis was only performed for the loose fabric structures. All the samples were coated with a thin layer of gold prior to SEM analysis.

The effects of the fibre type (acrylic waste fibre and virgin acrylic fibre) and the elastic yarn state (addition and type) on all the performance properties of the fabrics were statistically evaluated with ANOVA (Analysis of Variance) test, followed by post hoc test. ANOVA test evaluates whether any significant differences exist among two or more group means. Post hoc test determines which specific groups are statistically different from each other. The type of post hoc test was determined according to the Levene's test of homogeneity of variances. In the case that variance was not homogeneous ($p<0.05$), Tamhane's post hoc test was used and in the case that variance was homogeneous ($p>0.05$), SNK post hoc test was conducted. For all the statistical analyses, SPSS 23.0 program was used. The groups for the fibre type effect comprise recycled and acrylic fabric types. The groups for the elastic yarn state effect involve the fabrics with no elastic yarn, covered yarn and PBT yarn. All the experimental results were tested at the significance level of 0.05. To be able to evaluate parameters affecting the performance results of the fabrics in a broader perspective,

Table 3. Groups in ANOVA and post hoc tests

Test type	Parameter effect	Groups
ANOVA test	Fibre type effect	Recycled fabric
		Acrylic fabric
	Elastic yarn state effect	Fabric with no elastic yarn
		Fabric with covered yarn
		Fabric with PBT yarn
Post hoc test	Material type effect	Recycled with no elastic yarn
		Acrylic with no elastic yarn
		Recycled with covered yarn
		Acrylic with covered yarn
		Recycled with PBT yarn
		Acrylic with PBT yarn

fibre type and elastic yarn state effects, both of which were analysed separately in the ANOVA analysis were combined as a material type effect in the post hoc analysis. The groups for the material type effect in the post hoc test were called as recycled with no elastic yarn, acrylic with no elastic yarn, recycled with covered yarn, acrylic with covered yarn, recycled with PBT yarn and acrylic with PBT yarn. All the groups in the ANOVA and post hoc tests explained above are given in Table 3. In the post hoc results, subsets show which means of groups are significantly different from each other. The means placed in the same subset indicate that a set of means are not significantly different.

Results and Discussion

SEM Analysis Results

The SEM analysis results for the surface morphologies of the yarn and loose fabric types having six different materials are illustrated in Figures 3(a-f) and Figures 4(a-f), respectively. When the surface images of the recycled and virgin acrylic yarns with no elastic yarn and the fabrics made from these yarns are examined, it can be seen that the recycled acrylic yarns and fabrics exhibit quite smooth surfaces as well as virgin acrylic counterparts. Protruding fibres can be slightly noticed on the surface of these recycled yarns and fabrics. The effects of the covered and PBT elastic yarns on the fabric structural appearance can be clearly observed from the SEM photographs. As can be seen from the surface images, both the covered and PBT elastic yarns increase stitch densities and thickness of the fabrics, but the covered yarn makes them denser and thicker than the PBT yarn.

Dimensional Properties

The wale, course and stitch density results of the fabrics at

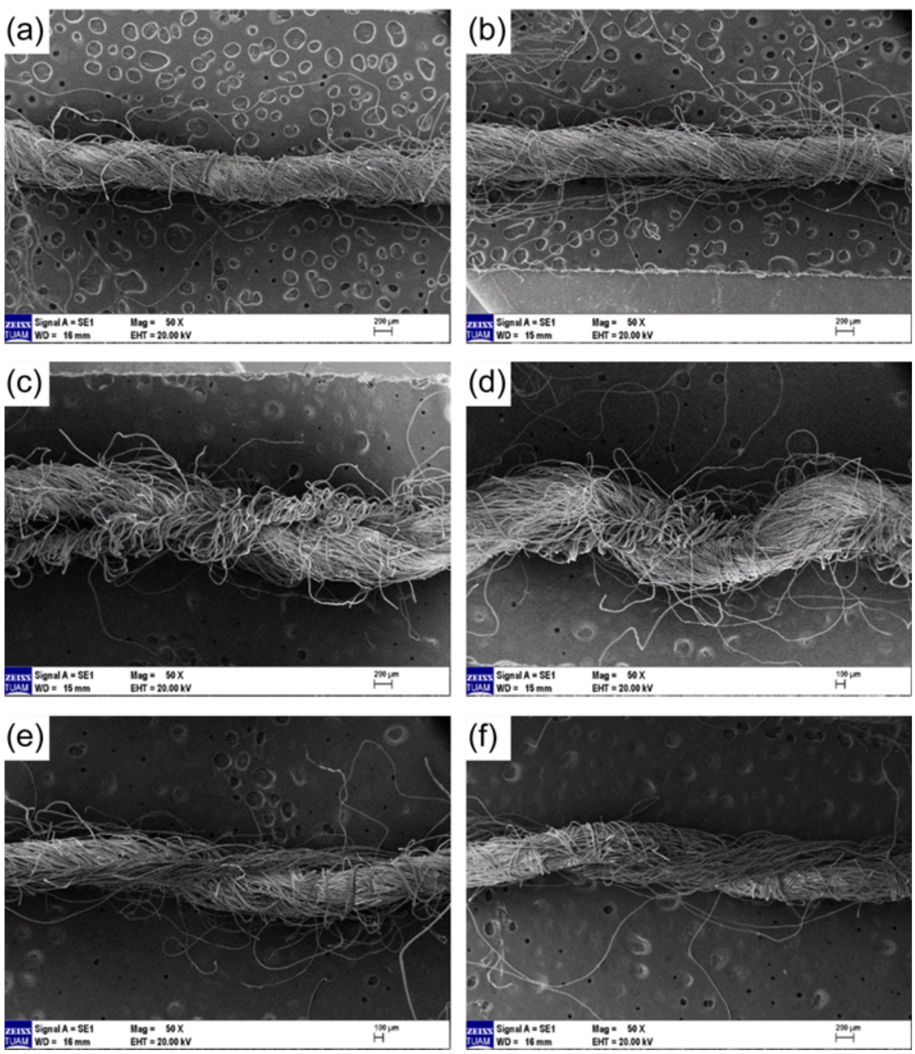

Figure 3. SEM images of (a) recycled acrylic yarn, (b) virgin acrylic yarn, (c) recycled acrylic/covered yarn, (d) virgin acrylic/covered yarn (e) recycled acrylic/PBT yarn, and (f) virgin acrylic/PBT yarn.

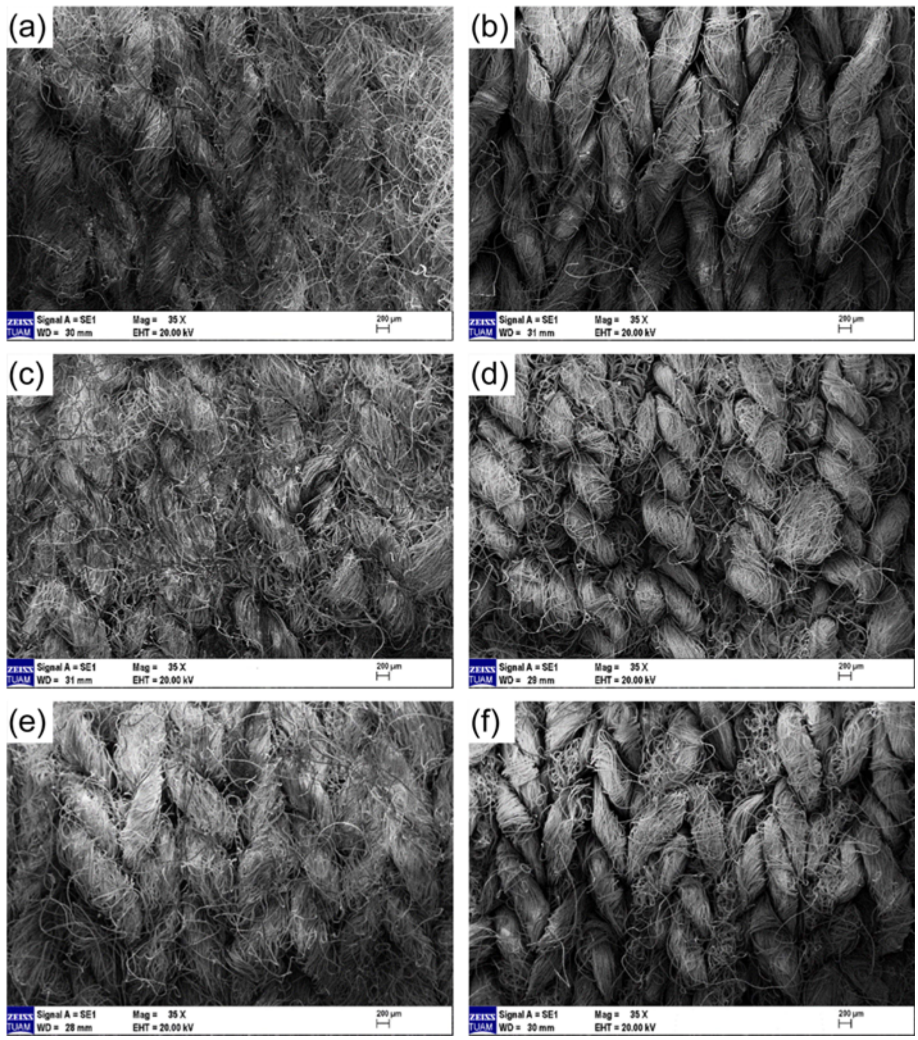

Figure 4. SEM images of (a) recycled fabric, (b) acrylic fabric, (c) recycled fabric with covered yarn, (d) acrylic fabric with covered yarn, (e) recycled fabric with PBT yarn, and (f) acrylic fabric with PBT yarn.

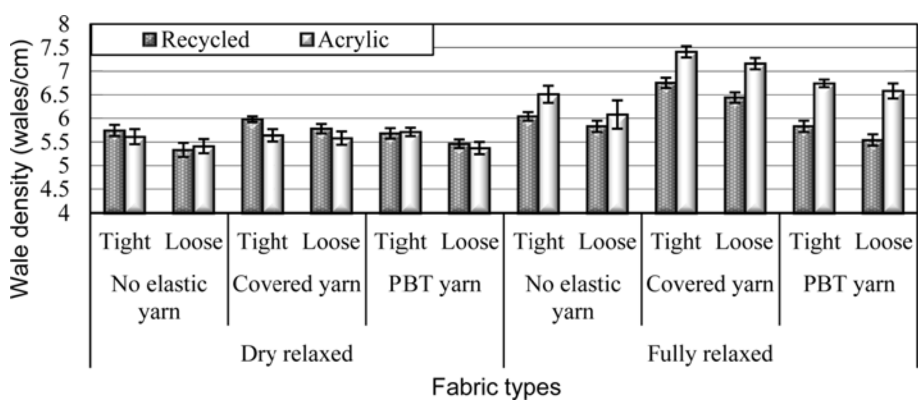

Figure 5. Wale density results of the fabrics.

their dry and fully relaxed states are given in Figures 5-7, respectively. From the wale, course and stitch density results, it is clear that apart from the course density values of the acrylic fabrics with no elastic yarn, the other density values of the recycled and acrylic fabrics increase as the relaxation process progresses. This result is in accordance

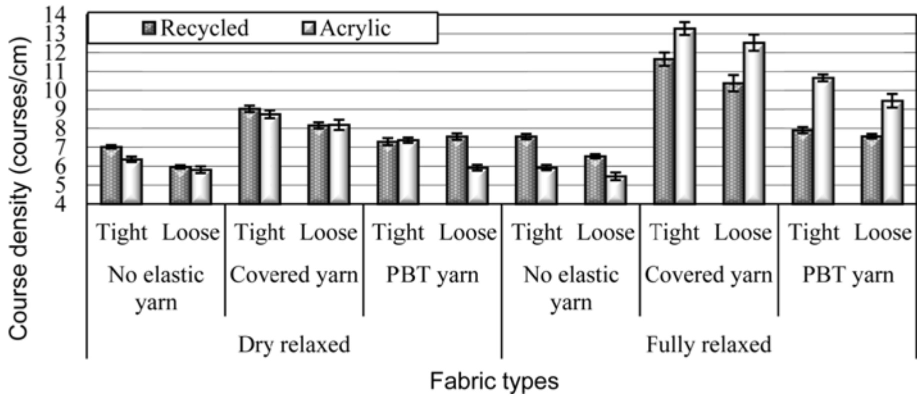

Figure 6. Course density results of the fabrics.

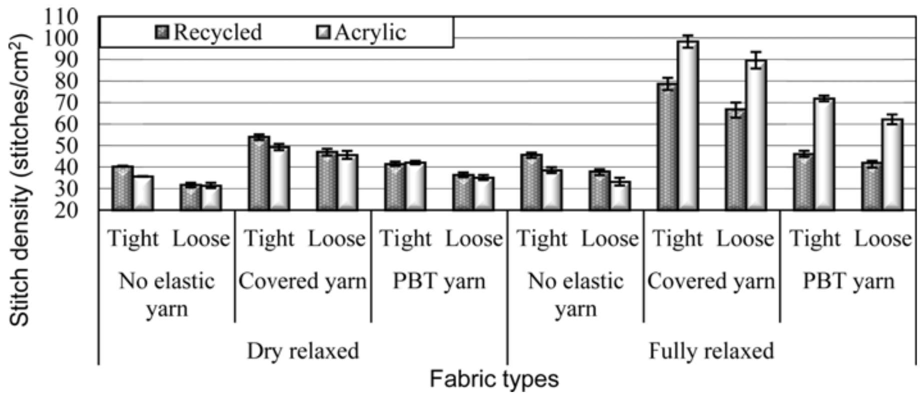

Figure 7. Stitch density results of the fabrics.

with the current understanding of behaviour of knitted fabrics after relaxation, as it is generally acknowledged that knitted fabrics tend to undergo dimensional changes when it is released from strains that are imparted to yarn during knitting process. Due to elastic recovery potential of the elastic yarns, yarn shrinkage also greatly contributes to the increase in density values. By the condition of minimum energy, fabrics are more completely released from strains and hence reach their completely stable configuration [20]. Full relaxation process, which includes washing and tumble drying treatments brings fabrics to their strain-free condition, in which internal energy is at its minimum. Therefore, the increases in the wale, course and stitch density values observed after full relaxation are caused by walewise and coursewise fabric shrinkages occurred as a result of relaxation of strains imparted during knitting process. However, the course density values of the acrylic fabrics with no elastic yarn do not reveal increase with the progress of relaxation. The removal of strains seems to affect the potential relaxation shrinkage of the acrylic fabrics only in wale direction rather than the course direction. High amount of walewise shrinkage of the acrylic fabrics appears to be accompanied by coursewise extension after full relaxation, which decreases course density values of these fabrics. As noted in the study of Postle [21], in some cases, an increase and the others a decrease.

All the fabric density results display that the waste fibre and acrylic fibre types seem to affect the fabric density results in the fully relaxed state rather than in the dry relaxed state. In the dry relaxed state, no appreciable differences between the most of the density values of the recycled and acrylic fabrics in both of the fabric tightness states were observed. This can be expected because dry relaxed state does not remove all the potential relaxation shrinkage as stated by Munden [20]. In their fully relaxed state, the differences between the density values of the recycled and acrylic fabrics increase due to different shrinkage behaviours of the fabrics in terms of the material.

When the fabric density values of the fully relaxed fabrics are investigated with respect to the fibre type effect, it can be seen that for the given fabric types with the covered elastic yarn and the PBT elastic yarn, the recycled fabrics display lower wale, course and stitch density values than the equivalent acrylic fabrics. In the fabrics with no elastic yarn, the wale density values of the recycled fabrics are also found to be less than those of the acrylic fabrics as in the case of the fabrics with the elastic yarn. These fabric density results seem to reflect the differences in elongation values of the recycled and acrylic yarns. As can be seen from Table 1, the recycled yarn has lower elongation value than the acrylic yarn. Therefore, the fabrics constructed from this recycled yarn are expected to reveal lower density values than the acrylic fabrics, because lower elongation value of yarn tends to decrease the shrinkage potential of the fabrics due to decrease in yarn relaxation. When the course and stitch density values of the recycled and acrylic fabrics with no elastic yarn are evaluated, it can be seen that these density values do not follow the same trend with the wale density values. In the fabrics with no elastic yarn, the recycled fabrics reveal higher course and stitch density values than the acrylic fabrics, which probably arise from the coursewise extension of the acrylic fabrics, due to revealing higher walewise shrinkage of the acrylic fabrics as explained above.

As far as the elastic yarn state is concerned, the fabrics with the covered yarn reveal the highest wale, course and stitch density values at their both dry and fully relaxed states. SEM images in Figures 4(a-f) also confirm the higher density results of the elastic fabrics. The covered yarn addition increases the stitch density values of the fully relaxed recycled and acrylic fabrics by the average of 74.1 % and 162.6 %, respectively. The fabrics with the PBT yarn display the second highest course and stitch density values at both of the relaxed states. With the PBT yarn addition, the stitch density values of the fully relaxed recycled and acrylic fabrics increase by the average of 5.7 % and 86.9 %, respectively. Elastic yarns affected the course density results more than the wale density values. Contribution of the PBT yarn to the wale density values is not observed for the recycled fabrics. The higher density results of the fabrics with the covered and PBT yarns can be explained by the high extensibility and recovery properties of these elastic yarns. As stated by Herath and Kang [22], elastic recovery property of the elastic yarns reduces stitch length due to yarn relaxation, which leads to increase in the fabric density values by increasing the shrinkage potential of the fabrics. As known, elastane fibre possesses high extensibility ranging from 200 % up to 800 % [8]. On the other hand, the extensibility of PBT fibre is range from 24 % to 29 % [8]. Since the elastane yarn in the covered yarn possesses higher extensibility than the PBT yarn, the contribution of the covered yarn to the density values is higher than the PBT yarn.

Figure 8 displays the dry and fully relaxed mass values of all the fabrics. The mass values reveal increases with the progression of the relaxation, except for the loose acrylic fabric with no elastic yarn. The highest mass values are obtained for the fully relaxed fabrics as in the case of the fabric density values. Comparison of the mass values of the fabrics on the basis of the fibre type reveals that whilst the recycled fabrics with no elastic yarn have higher mass values than the equivalent acrylic fabrics, the recycled fabrics with the covered yarn and PBT yarn conversely reveal lower mass values than the equivalent acrylic fabrics. For both of the relaxation states, the fabrics with the covered yarn display the highest mass values, followed by the fabrics with the PBT yarn. When the covered yarn is added to the fabrics, the mass values of the fully relaxed recycled and acrylic fabrics increase by the average of 81.2 % and 228.78 %, respectively. The PBT yarn addition increases the mass values of the fully relaxed recycled and acrylic fabrics by the average of 14.14 % and 105.6 %, respectively. From the results, it can be seen that the covered yarn increases the mass values more than the PBT yarn, when they are added to the fabrics. The mass values of the fabrics seem to a large extent reflect the stitch density values. Bivariate correlation analysis also confirms that there is high positive significantly important correlation (0.98) between the stitch density and the mass. In addition to this, the count of the elastic yarn is also another reason for the increases in the mass values noted after the additions of the elastic yarn types.

Corresponding to the fully relaxed thickness results in Figure 9, the recycled fabrics show greater thickness values than the acrylic counterparts. This results may be partly

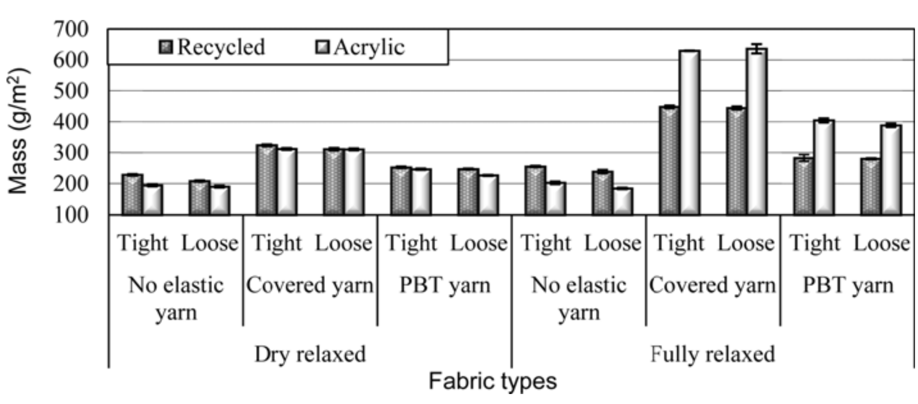

Figure 8. Mass results of the fabrics.

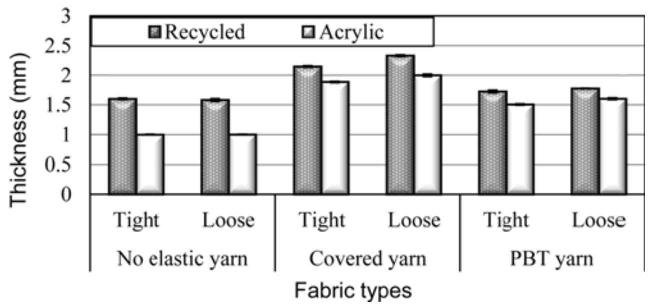

Figure 9. Thickness results of the fabrics.

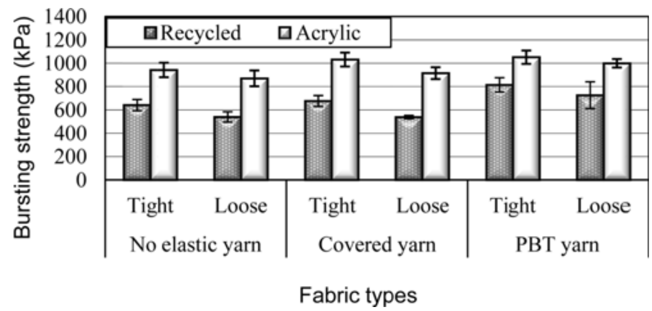

Figure 10. Bursting strength results of the fabrics.

results from the slightly higher hairiness values of the recycled yarn than the acrylic yarn in Table 1. For the fabrics with no elastic yarn, the higher stitch density and mass values of the recycled fabrics than the equivalent acrylic fabrics seem to contribute the thickness values as well. When the thickness results are evaluated according to the elastic yarn state, it can be seen that the fabrics with no elastic yarn reveal the lowest thickness values. It is followed by the fabrics with the PBT yarn and the covered yarn, respectively. While the covered yarn increases the thickness values of the recycled and acrylic fabrics by the average of 40.7 % and 94.39 %, respectively, the PBT yarn increases the equivalent values of the recycled and acrylic fabrics by the average values of 10.1 % and 55.6 %. These results reveal that the covered yarn increases the thickness values of the fabrics more than the PBT yarn. This is because the fabrics with the covered yarn have higher fabric density and mass values than those with the PBT yarn.

The ANOVA analysis performed for the dimensional properties of the fabrics demonstrated that the fibre type and the elastic yarn state affected all the stitch density, mass and thickness results significantly (for all the effects, $p<0.05$).

Bursting Strength Results

The bursting strength is the measure of strength applied in all directions to rupture a fabric [23,24]. It is well known that bursting strength of a fabric is related to yarn strength and is greatly affected by fabric extensibility, which is mainly determined by fabric structure and fibre/yarn extensibility [24]. Especially, fibre and yarn tensile properties to a lesser or greater extent play important role on bursting strength [24]. Moreover, thickness, mass and density properties of fabrics also affect bursting strength. Comparison of the bursting strength results in terms of the fibre type in Figure 10 shows that the recycled fabrics show lower bursting strength results than the acrylic fabrics for all the fabric types with no elastic yarn and with elastic yarn. This finding is in accordance with the studies of Yuksekkaya *et al.* [15] and Gun *et al.* [13]. The bursting strength results of the fabrics appear to reflect the tenacity values of the recycled and acrylic yarns. As given in Table 1, the tenacity value of the recycled yarn is distinctively lower than that of the acrylic yarn, which decreases the bursting strength values of the recycled fabrics. In regard to the elastic yarn state, the fabrics with the PBT yarn reveal the highest bursting strength values, followed by those with the covered yarn except for the loose recycled fabric with the covered yarn. The lowest bursting strength results are observed for the fabrics with no elastic yarn. The loose recycled fabrics with the covered yarn and with no elastic yarn reveal very close bursting strength values. As consistent with the present results, Ertekin *et al.* [25] and Gun *et al.* [13] also reported that fabrics with elastane yarn had higher bursting strength results than those without elastane. By using the PBT yarn, the bursting strengths are improved by about the average of 30.8 % for the recycled fabric type and the average of 13.2 % for the acrylic fabric type. The improvements on the bursting strength for the recycled and acrylic fabrics with the covered yarn are the average of 2.6 % and 7.3 %, respectively. It is evident that the addition of both of the elastic yarns improves the bursting strength results of both the recycled and acrylic fabrics. The improvement is greater in the fabrics with the PBT yarn than in the fabrics with the covered yarn. The tighter, heavier and thicker construction of the fabrics with elastic yarn seem to increase the resistance towards applied bursting force since a greater number of stitches and fibres meets bursting force. A high extensibility property of the elastic yarns may also be another reason for higher bursting strength results of these fabrics with the elastic yarn than those of the fabrics with no elastic yarn. The PBT yarn consists of 100 % polyester fibres of high tenacity. On the other hand, in addition to polyester fibre, the covered yarn also includes lycra, which is in general weak fibre [6]. Therefore, the reason that the fabrics with the covered yarn reveals lower bursting results than those with the PBT yarn may be attributed to lycra fibre in the covered yarn.

It is observed from the ANOVA analysis that the fibre type and the elastic yarn state significantly affect the bursting strength results ($p<0.05$). Regarding to the SNK post hoc test results in Table 4, the fabrics having six different material types are divided into four different sub groups

Table 4. Post hoc test results for the bursting strength values

Fabric types	N	Subsets (p<0.05)			
		1	2	3	4
Recycled with no elastic yarn	10	590.11			
Recycled with covered yarn	10	606.91			
Recycled with PBT yarn	10		769.70		
Acrylic with no elastic yarn	10			906.11	
Acrylic with covered yarn	10			973.05	973.05
Acrylic with PBT yarn	10				1025.25

according to the bursting strength values. In both of the recycled and virgin acrylic fabric types, the fabric types with no elastic yarn and with the covered yarn affect the bursting strength values in similar way. Based on this statistical result, the covered yarn has not statistically significant influence on the bursting strength values of the recycled and acrylic fabrics. The lowest bursting strength value is observed for the recycled fabric types with no elastic yarn and with the covered yarn. On the other hand, the acrylic fabrics with the covered yarn and PBT yarn have the highest bursting strength value.

Pilling Results

Pilling is a kind of fabric fault occurring by entanglement of loose fibres protruding from fabric surface during wear and washing [26]. In this study, with pilling test, the formation of pills on the fabric surface are evaluated as grade. There are many factors influencing pilling formation among which are fibre fineness and length, blend composition, yarn hairiness, fabric compactness, etc. [26]. The pilling results of all the fabrics are given in Figure 11. In regard to the fibre type, the recycled fabrics exhibit much higher pilling tendency than the corresponding acrylic fabrics. This result may partly arise from the higher hairiness of the recycled yarn as compared with that of the acrylic yarn (Table 1). Acrylic waste fibres have varying fibre lengths with a high amount of short fibres (Figure 2). Short fibres in the recycled fabric structure may also promote formation of pilling because short fibres tend to migrate to the surface of a fabric in the case of application of mechanical action to fabric surface [26].

The addition of the elastic yarns appears to improve the pilling tendency of the recycled fabrics. The PBT yarn seems to reduce the pilling tendency of the recycled fabrics more than that of the covered yarn. As far as the acrylic fabrics are concerned, the addition of the PBT yarn only reduces the pilling tendency by half a degree for the tight fabric structure. The positive effect of both of the elastic yarns on the pilling results is not observed for the rest of the acrylic fabrics. The lower pilling tendency of the recycled fabrics with the elastic yarn than those with no elastic yarn may be results from that these fabrics have tighter construction and higher extensibility property, because this kind of fabric structure may prevent the migration of fibres from interior of the fabric to surface. The reason that the elastic yarn positively affects the recycled fabrics rather than the acrylic fabrics may be that the recycled fabric with no elastic yarn have much higher pilling tendency results than the equivalent acrylic fabrics.

Abrasion Results

Abrasion is a kind of mechanical deterioration occurring on a surface of fabric exposed to rubbing or abrasive loads. Abrasion mainly results from the gradual removal of damaged/broken fibre fragments and complete fibres [24]. Therefore, the factors affecting fibre mobility in a fabric will influence abrasion behaviour of fabrics. An increase in fabric tightness, thickness and mass decrease abrasion [24]. Moreover, the fibre properties, such as strength, elongation and elastic recovery are the other important influential factors for abrasion behaviour [24]. In this study, as a measurement method of abrasion, mass losses occurring as a result of the abrasion cycles of 5000, 10000, 15000 and 20000 are used. According to the mass loss results of all the fabrics in Figure 12, the mass loss values increased gradually with the increase of the abrasion cycles because the fabrics were exposed to more abrasive forces. In the fabrics with no elastic yarn and with the elastic yarn, the recycled fabrics possess lower mass loss values than the equivalent acrylic fabrics. This is in agreement with the results of the previous study [13], in which recycled cotton socks reveal better abrasion resistance results than virgin

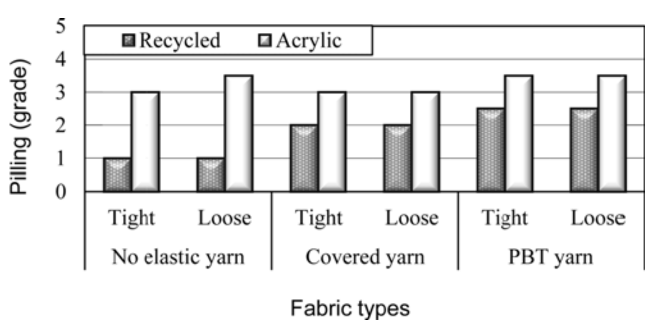

Figure 11. Pilling results of the fabrics.

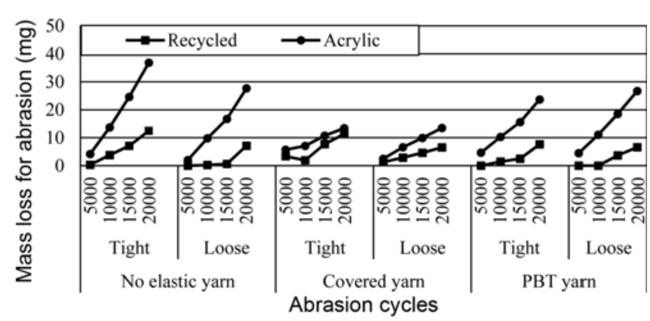

Figure 12. Mass loss results of the fabrics for abrasion.

cotton socks. The differences between the mass loss values of the recycled and acrylic fabrics are the highest for the fabrics with no elastic yarn when compared to those of counterparts with the covered and PBT yarns. The lower mass loss tendency of the recycled fabrics with no elastic yarn than the equivalent acrylic fabrics could be explained by their higher stitch density, thickness and mass values. As stated above, an increase in any of these fabric structural properties has a tendency to decrease abrasion. For the fabrics with elastic yarn, the differences between stitch density and mass values of the recycled and acrylic fabrics do not seem to have effect on mass loss values. This probably results from the tight structure of the fabrics with elastic yarn. The lower mass loss tendency of the recycled fabrics with elastic yarn than the equivalent acrylic fabrics might be attributed to their higher thickness values. From Table 5, it can be seen that due to having the tightest structure, the mass loss difference between these two recycled and acrylic fabric types with the covered yarn is found to be statistically insignificant ($p>0.05$).

As far as the elastic yarn state is concerned, the fabrics with the elastic yarn tend to reveal lower mass loss values than the corresponding fabrics with no elastic yarn at the end of the 20000 abrasion cycle. In agreement with the previous study done by Gun *et al.* [13], the addition of the covered and PBT yarns improved the mass loss results of the recycled and acrylic fabrics. When the mass loss values of the acrylic fabrics with the covered yarn and the PBT yarn are compared with each other, the acrylic fabrics with the covered yarn appear to reveal lesser mass loss values than those with the PBT yarn. However, for the recycled fabrics, no specific trend on the mass loss values in terms of the elastic yarn type is observed. The tighter structure and elastic property of the fabrics with the elastic yarn may increase the cohesion between fibres in the fabric structure and thus, prevent the removal of fibres from the fabric structure. Moreover, the higher thickness and mass values of the fabrics with the elastic yarn may also be the other factors for the better abrasion results.

Regarding to the ANOVA analysis, the effects of the fibre type and the elastic yarn state on the mass loss results are statistically important ($p<0.05$). The Tamhane's test results performed for the material type effect on the mass loss values obtained after 20000 abrasion cycles are given in Table 5. The fabric types are divided into three different groups in terms of the mass loss values. Irrespective of the elastic yarn state, it can be confirmed that the recycled fabrics have statistically significant lower mass loss values than the acrylic fabrics, which means that the recycled fabrics have better abrasion resistance. The differences between the mass loss values of all the recycled fabrics with no elastic yarn and with elastic yarn are found to be statistically insignificant and these three fabric types have the lowest mass loss values and hence the best abrasion resistance. The highest mass loss value is obtained for the acrylic fabric type with no elastic yarn.

Table 5. Post hoc test results for the mass loss values for the abrasion

Fabric types	N	Subsets ($p<0.05$)		
		1	2	3
Recycled with PBT yarn	6	7.12		
Recycled with covered yarn	6	8.93	8.93	
Recycled with no elastic yarn	6	9.80	9.80	
Acrylic with covered yarn	6		13.43	
Acrylic with PBT yarn	6			25.17
Acrylic with no elastic yarn	6			32.23

Extension Results

The extension is a measure of how easily the fabric stretches at a given load [27]. The walewise and coursewise extension results are displayed in Figures 13 and 14, respectively. The coursewise extension is higher than that of the walewise extension. This can be expected because two lengths of yarn in parallel supporting the load during walewise extension, whereas these are spread out into one sinle length during coursewise extension [28]. Correspondingg to Figure 13, in the fabrics with no elastic yarn, the recycled fabrics exhibit higher walewise extension than the acrylic fabrics. On the other hand, in the fabrics with the elastic yarn, a reverse trend is obtained in that the recycled fabrics tend to reveal slightly lower walewise extension results than the acrylic counterparts. The difference between the walewise extension results of the recycled and acrylic fabrics is more marked in the fabrics with no elastic yarn than in those with the elastic yarn. On the basis of the elastic yarn state effect, it can be observed that the highest walewise extension results are obtained for the fabrics with the covered yarn, followed by those with the PBT yarn and with no elastic yarn, in turn. The walewise extension results to a great extend appear to reflect the elastic yarn elongation values. The highest elongation value of the elastane fibre in

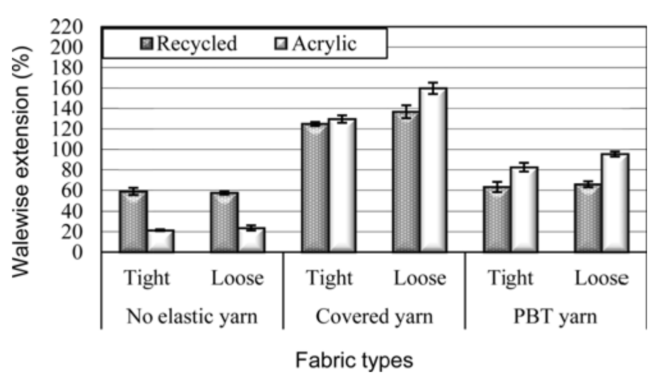

Figure 13. Walewise extension results of the fabrics.

Table 6. Post hoc test results for the walewise extension values

Fabric types	N	Subsets (p<0.05)				
		1	2	3	4	5
Acrylic with no elastic yarn	10	22.54				
Recycled with no elastic yarn	10		58.08			
Recycled with PBT yarn	10			64.42		
Acrylic with PBT yarn	10				88.19	
Recycled with covered yarn	10					130.77
Acrylic with covered yarn	10					144.62

Table 7. Post hoc test results for the coursewise extension values

Fabric types	N	Subsets (p<0.05)		
		1	2	3
Acrylic with PBT yarn	10	114.61		
Recycled with PBT yarn	10	120.80		
Acrylic with covered yarn	10	126.51	126.51	
Acrylic with no elastic yarn	10		137.29	137.29
Recycled with covered yarn	10			148.87
Recycled with no elastic yarn	10			150.91

the covered yarn results in the highest walewise extension.

The Tamhane's test results in Table 6 indicate that the fabric types are divided into five different subsets in terms of the walewise extension values. No statistically significant difference between the walewise extension results of the recycled and acrylic fabric types with the covered yarn was seen. The highest walewise extension result is obtained for the fabrics with the covered yarn. The acrylic fabric type with no elastic yarn has the lowest walewise extensibility.

When compared to the walewise extension results, it can be seen that the coursewise extension results of the fabrics in Figure 14 is very close to each other. With one exception involving the loose fabric type with the PBT yarn, the recycled fabrics tend to reveal slightly higher coursewise extension results than the similar acrylic fabrics. Comparison of the coursewise extension results with regard to the elastic yarn state shows that the fabrics with no elastic yarn tend to have the highest coursewise extension results, followed by those with the covered yarn. The only exception for this result occurred for the tight recycled fabric. Irrespective of the fibre type, the lowest coursewise extension results are obtained for the fabrics with the PBT yarn. The trend that the fabrics with no elastic yarn have higher coursewise extension results than those with the elastic yarn was also recorded in the study of Kizildag *et al.* [29], who observed that cotton fabrics with no spandex had higher coursewise extension results than those with spandex. As stated in this previous study [29], an increased tightness of the fabrics

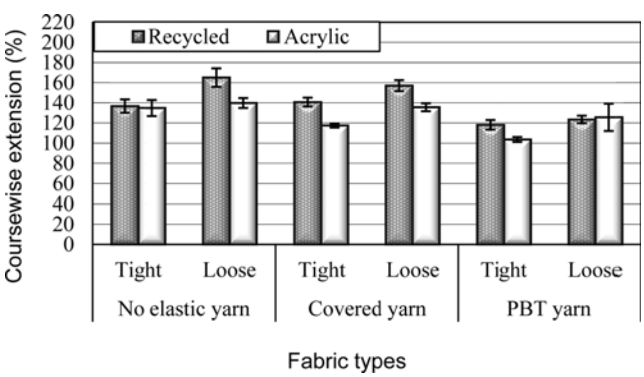

Figure 14. Coursewise extension results of the fabrics.

with the elastic yarn addition might have increased the elasticity modulus of these type of the fabrics due to inner pressure of fabrics.

According to the ANOVA analysis, the fibre type and the elastic yarn state significantly affect the coursewise extension results ($p<0.05$). The Tamhane's results in Table 7 reveal that the coursewise results are separated into three subsets in terms of the material type. No statistically significant differences are seen between the coursewise extension results of the recycled and acrylic fabrics with no elastic yarn and the recycled with the covered yarn. The highest coursewise extension results are obtained for these latter fabric types. The recycled and acrylic fabric types with the PBT yarn and the acrylic fabric type with the covered yarn affected the coursewise results in a similar way and displayed the lowest coursewise results.

Conclusion

In this proposed study, the performance properties of the recycled acrylic fabrics with no elastic yarn, with the covered yarn and with the PBT yarn are investigated and the results are compared with those of the corresponding virgin acrylic fabrics. The effects of the acrylic fibre type (waste fibre and virgin fibre) and the elastic yarn state (addition and type) on the performance properties of the fabrics are analysed with the ANOVA and post hoc tests. As performance properties of the fabrics, fabric dimensional parameters (fabric density values, mass and thickness), bursting strength, pilling, abrasion and extension values are considered. Based on the ANOVA analysis, it is obtained that the fibre type and the elastic yarn state have statistically significant influence on all the performance properties of the fabrics ($p<0.05$). When the fibre type effect is concerned, it is observed that the recycled acrylic fabrics exhibit higher thickness, abrasion resistance, pilling tendency and coursewise extension results and lower wale density and bursting strength results than the equivalent virgin acrylic fabrics. The recycled and acrylic fabrics reveal different tendency for the course density, stitch density, walewise extension values in terms of the elastic yarn addition and type.

Regarding to the elastic yarn state, it is observed that the fabrics with the covered yarn show the highest stitch density, mass, thickness and walewise extension results, followed by the fabrics with the PBT yarn. The highest bursting strength and the lowest pilling tendency results are obtained for the fabrics with the PBT yarn. Both of the elastic yarns improve the abrasion resistance of the recycled and acrylic fabrics. The difference between the abrasion results of the recycled fabrics with the covered yarn and the PBT yarn is found to be insignificant. On the other hand, the acrylic fabrics with the covered yarn exhibit better abrasion resistance values than those with the PBT yarn. Both the covered and PBT elastic yarns gain significant benefits to the recycled fabrics in terms of performance properties as a result of structural changes imparting to the fabrics due to elastic property.

All the results reveal that acrylic fibre waste can be used in the production of the sweater like plain knitted fabrics in acceptable quality as a cheap alternative to virgin acrylic fibre and with the elastic yarn addition, the quality and performance properties of the fabrics can be improved and some advantageous properties can be gained to fabrics.

This study contributes to existing literature through introducing information on the performance properties of recycled acrylic knitted fabrics made from 100 % acrylic fibre wastes in comparison with those of virgin acrylic counterparts and improving low performance properties of these fabrics for suitability in added value applications such as sweater like knitted fabrics by using another promising approach of elastic yarn addition.

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