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Effect of Some Process Parameters on Acrylic Yarns and Knitted Fabrics Made of Those Yarns

Akrilik İplikler ve Bu İpliklerden Üretilen Örme Kumaş Özelliklerine Bazı Üretim Parametrelerinin Etkisi

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EFFECT OF SOME PROCESS PARAMETERS ON ACRYLIC YARNS AND KNITTED FABRICS MADE OF THOSE YARNS

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ABSTRACT: High bulk acrylic yarns having relax and unrelax fibre blends with varying ratios are commonly used for knitted fabrics. Within acrylic yarn production, bulking process parameters and blending ratio of relax and unrelax acrylic fiber have considerable effect on the desired yarn volume as well as on optimum yarn properties. This study aimed to investigate the effect of ply twist (tpm), bulking temperature (°C) and bulking machine velocity (m/sec) on acrylic yarn properties as well as on supreme knitted fabric properties from those yarns where a constant blend ratio of relax/unrelax acrylic fibre blends were utilized. For this purpose, three different ply twist (185, 215 and 245 tpm) and bulking machine velocity of three levels (550, 650 and 750 m/sec) were selected. Bulking process was achieved at 110 and 130 °C. Tenacity, elongation, crimp contraction and shrinkage properties of untreated acrylic yarns and of acrylic yarns treated with bulking process were evaluated. Additionally, weft knitted fabrics from those yarns were produced at constant production parameters. Bursting strength, air permeability and pilling properties of acrylic knitted fabrics were compared. In order to obtain the optimum ply twist, bulking temperature and bulking machine velocity regarding to desired yarn and fabric properties, numerical optimization method was used at 5% significance level. According to the test results; it was concluded that ply twist, bulking temperature and bulking machine velocity had significant effect on yarn shrinkage. In addition, interaction of ply twist and bulking temperature was found to be an influential factor on bursting strength, bursting distention and air permeability properties. As a consequence, desirability ratio with the value of 57.2% could be provided for the fabrics with the acrylic yarns produced at 185 tpm ply twist with 614 m/sec bulking machine velocity at 130 °C bulking temperature.

Keywords: Acrylic fibre, bulking process, high bulk yarn, knitted fabric, optimization.

AKRİLİK İPLİKLER VE BU İPLİKLERDEN ÜRETİLEN ÖRME KUMAŞ ÖZELLİKLERİNE BAZI ÜRETİM PARAMETRELERİNİN ETKİSİ

ÖZET: Değişen oranlarda relakse ve relakse olmamış akrilik liflerin karıştırılmasıyla üretilen yüksek hacimli akrilik iplikler örme kumaşlarda yaygın olarak kullanılmaktadır. Burada, şişirme işlem parametreleri ve relakse/relakse olmamış akrilik liflerinin karışım oranı, istenen iplik hacmi ve optimum iplik özellikleri üzerinde önemli etkiye sahiptir. Bu çalışma kapsamında, sabit karışım oranında relakse/relakse olmamış akrilik lifleri kullanılarak farklı kat bükümünde (tpm), şişirme sıcaklığında (°C) ve şişirme makine hızında (m/sn) üretilmiş iplikler ve bu ipliklerden üretilen örme kumaş özellikleri belirlenmeye çalışılmıştır. Bu amaçla, üç farklı kat büküm (185, 215 ve 245 tpm) ve şişirme makine hızı (550, 650 ve 750 m/sn) seçilmiştir. 110 ve 130 ° C'de şişirme işlemi gerçekleştirilmiştir. Şişirme işlemi yapılmamış ve yapılmış iplik numunelerinin mukavemet, uzama, kıvrım kısalması ve çekme özellikleri belirlenmiştir. Bu iplikler kullanılarak sabit üretim parametrelerinde atkılı örme kumaşlar üretilmiştir. Kumaş numunelerinin patlama mukavemeti, patlama uzaması, hava geçirgenliği ve boncuklanma özellikleri belirlenmiştir. İstenilen iplik ve kumaş özelliklerine göre optimum kat bükümü, şişirme sıcaklığı ve şişirme makine hızını elde etmek için %5 önem seviyesinde sayısal optimizasyon metodu kullanılmıştır. Test sonuçlarına göre; kat bükümü, şişirme sıcaklığı ve şişirme makinesi hızının iplik çekme özelliği üzerinde önemli bir etkiye sahip olduğu belirlenmiştir. Buna ek olarak, kat bükümünün ve şişirme sıcaklığının etkileşiminin patlama mukavemeti, patlama yüksekliği ve hava geçirgenliği üzerinde önemli bir etkiye sahip olduğu bulunmuştur.

Sonuç olarak, istenilen hedefe ulaşma oranı %57,2 olan, 185 tpm kat bükümlü 614 m/sn şişirme makinesi hızında ve 130 °C şişirme sıcaklığında üretilen akrilik iplik ve bu iplikten elde edilen örme kumaşta sağlanmıştır.

Anahtar Kelimeler: Akrilik lifi, şişirme prosesi, yüksek hacimli iplik, örme kumaş, optimizasyon.

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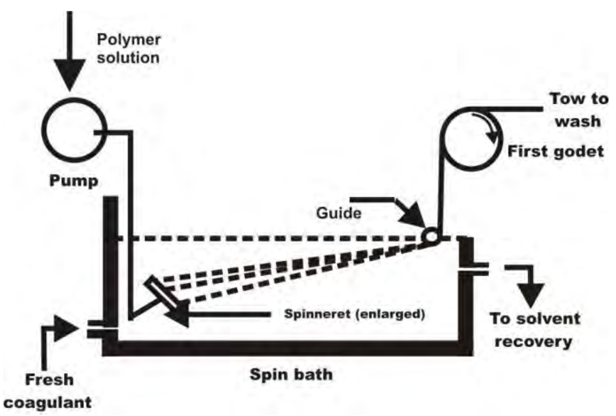
1. INTRODUCTION

Due to the low cost of "acrylonitrile", acrylic fibre gained importance with its resemblance to wool yarn character for the knit wears. There has been a great tendency especially towards the high bulk yarn production where the yarn volume is increased which results with the improvement in handling, covering and thermal insulating properties of end products [1]. Exploratory studies on comparison of acrylic based bulk yarns produced in different spinning systems are available in literature. During the 1950's, at least 18 companies had focused on acrylic fibre production. However, during 1970's there has been rapid growth of acrylic fibre production in Japan, Eastern Europe and developing countries [2]. Most of the acrylic fibres are spun by dry spinning in which the removal of solvent in hot air results with fibre forming or by wet spinning in which the fibre is formed by a diffusion process. Simple schematic of an acrylic fibre in wet (a) and dry (b) spinning is indicated in Figure 1. Melt spinning is not commercially applied owing to acrylic fibres decomposing before their melting points.

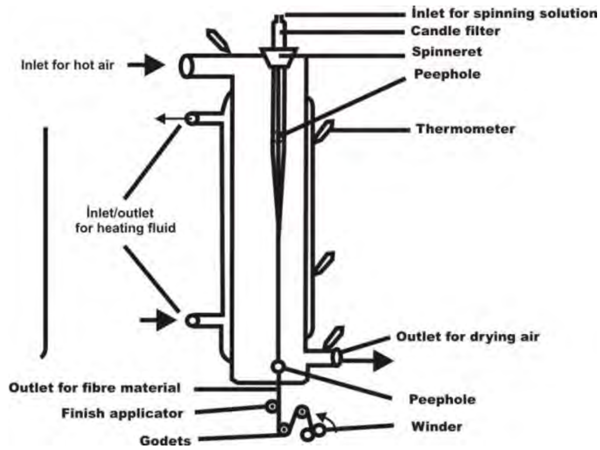
For tow end-uses of the acrylic fibres, the fibres from each spinning cell on each half of the machine are combined together making a large tow of up to 500 000 dtex. These are drawn off by take-off rollers at speeds of 250–450 m/min, prior to collection in spin cans. The second stage of acrylic production includes a series of some processes such as drawing, washing, finishing, drying, and crimping. The crimped tow is later cut to different staple lengths for staple spinning [1, 3-5].

Bulking mechanism is obtained by utilizing the difference in shrinkage power of acrylic fibres which results with a modified structure of the spun yarns known as high-bulked structure [6]. Piller (1973) presented a model for the position of unrelaxed and relax fibres in high bulked acrylic yarn. When the acrylic yarns are exposed to heating relaxation conditions by steaming or hot air treatment, the shrinkable fibre groups' contract and non-shrinkable fibres move towards the yarn surface (Figure 2).

Bulking mechanism in high-bulk yarns depends not only on contractile properties of fibres' shrinkage properties but also on the interaction of two components (relaxed-unrelaxed) within the yarn. The yarns' internal structure factors including fibre blend proportions, yarn twist, radial distribution of the two components relative to the yarns axis are influencing factors for the acrylic yarn properties.



(a)



(b)

Figure 1. Schematic view of wet spinning (a), dry spinning (b) [2].

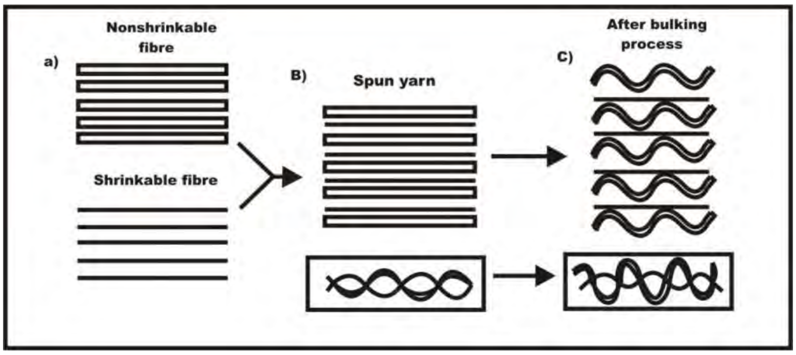


Figure 2. Piller's theory for effect of different shrinkable acrylic fibre in yarn structure [4].

There are some early studies in the literature related to investigation of acrylic and/or acrylic blend yarn production parameters as well as their effects on yarn and fabric properties [1,5, 7-23]. High-bulk acrylic yarns (steamed and dyed) with different shrinkable fibre blending ratios were produced in one of the study where the effect of blending ratios of relax and unrelaxed tows on yarn shrinkage, yarn specific volume and yarn tensile properties were evaluated. The authors concluded that the increment in the shrinkable fibre blending ratio (up to 40 %) led to increment of yarn shrinkage but led to decrement for tensile strengths. However further increase in shrinkable fibre ratio did not significantly influence the yarn shrinkage values at significance level of 0.05 [5]. Bakhtiari et al. also conducted a research related to effect of shrinkable acrylic fibre blend ratios on knitted fabric compression energy (WC) and surface thickness (ΔT). It was concluded that as the shrinkable acrylic fibre blend ratios (%) increased up to 40%, compression energy and surface thickness also increased however further increase in shrinkable fibre ratio (%) resulted with the decrease in the mentioned results [7].

Non-shrinkable and shrinkable (high bulk) acrylic fibres with different initial modulus were used with different percentages in order to produce five kinds of yarns and twill woven fabrics made of those yarns. Results of pilling test performed on the sample indicated that by increasing the percentage of non-shrinkable (regular) fibres with high initial modulus, fibres had tendency to leave the yarn structure which resulted with higher pilling [9]. Wool and acrylic blended worsted yarns with a linear density of 32 tex (31 Nm) and twist level of 414 tpm at different blend ratios (75/25, 50/50 and 25/75) were evaluated in another study. Yarn cross-sections with pre-dyed fibres were observed with the digital image capturing system. Via a mathematical technique on bitmap data, index of blend irregularities, fibre cluster sizes and fibre migration were evaluated. The results revealed a good correlation between the proposed image processing technique and the visual method. It was also deduced that acrylic fibre was generally positioned in the outer layer of blended yarns conversely wool fibre migrated towards the inner layer of blended yarns [10].

Although many studies related to effect of process parameters such as blending ratio (%), relaxation time or temperature on acrylic/acrylic blend yarns' and fabrics' physical, mechanical properties have been conducted, there are not many researches comprising the influence of ply twist, bulking temperature (°C) and bulking machine velocity (m/s) parameters on ply folded acrylic yarns as well as with the optimization of the properties. The main objective of this work focuses on the evaluation of effect of ply twist, bulking temperature and bulking machine velocity on tensile and elongation properties of folded acrylic yarns as well as on bursting strength (kPa), bursting distension (mm) and air permeability (mm/sec) of knitted fabrics made of those yarns. Additionally, main objective of this work was to investigate the coincident optimization of all yarns and fabrics properties based on Numerical Optimization Method.

2. MATERIAL AND METHOD

In this research, acrylic tow with nominal fibre fineness of 2.75 denier, tenacity of 9.5-10 gf/tex and tow elongation of 18-19 % was used for the high bulk acrylic production. Having utilized a tow-to-top stretch-breaking machine (SEYDEL), two different shrinkable and non-shrinkable acrylic fibre tops with linear densities of 120 ktex were produced with the drawing ratio of 4.85. Shrinkable and non-shrinkable acrylic tops were then blended with shrinkable fibre blending ratios of 60%-40% relax/unrelax acrylic fibre on a NSC brand blender gilling machine. Produced blended slivers passed through standard worsted spinning preparation machines and final acrylic yarn of Nm 35/1 (Z) was produced at 9500 rpm spindle speed with twist of 215 tpm. Two folded acrylic yarns were produced at three twisting levels as 185, 215 and 245 tpm respectively using standard two-for-one twister machines. Following the ply twisting, the acrylic yarns were exposed to bulking process which was carried out by using Volofil continuous bulking system. Three bulking machine velocity levels were selected as 550, 650 and 750 m/sec and two bulking temperature was selected as 110 and 130°C. Additionally, for the evaluation of the bulking process effect, the folded yarn groups of 185, 215 and 245 tpm were not treated with bulking process. The experimental design is indicated in Table 1. In total, 21 types of acrylic yarns were utilized from for the knitting process of single jersey fabrics on Tianyuan brand weft knitting machine where the knitting process parameters were kept constant.

Table 1. Experimental Design

Number	Ply Twist (tpm)	Bulking Temperature (°C)	Bulking Velocity (m/s)
1	185	Untreated	
2	215		
3	245		
4	185	110	550
5	185	110	650
6	185	110	750
7	215	110	550
8	215	110	650
9	215	110	750
10	245	110	550
11	245	110	650
12	245	110	750
13	185	130	550
14	185	130	650
15	185	130	750
16	215	130	550
17	215	130	650
18	215	130	750
19	245	130	550
20	245	130	650
21	245	130	750

All the yarn and fabric test measurements were conducted under standard test conditions of 65 ± 2% relative humidity and 21 ± 1 °C temperature according to ISO 139:2005 standard. Yarn tensile properties were conducted at 250 mm jaw distance and 250 mm/min test speed in accordance with ISO 2062 standard by means of Titan 2 Universal strength tester. Crimp contraction test was carried out at 2 cN/tex initial load for 10 seconds and processing continued with 0.01 cN/tex load for 10 minutes at 135°C test temperature by using Texturmat ME+ device in accordance with EN 14621 standard. For the calculation of yarn crimp contraction, equation (1) given below was determined

$$Crimp\ Contraction\ (CC\%) = \frac{l_g - l_z}{l_g} x100 \qquad (1)$$

where; $l_g$is length of yarn in mm at the initial load (2 cN/tex) stage after 10 seconds loading period and l_z is the length of yarn in mm at next load stage (0.01 cN/tex) after 10 minutes loading period.

Yarn shrinkage was also evaluated according to EN 14621 standard. Testing procedure is based on calculation of the shrinkage (%) of yarn samples after thermal treatment at 135°C for 10 minutes. The initial yarn length at 2 cN/tex load is determined as (l_{g_1}) and the yarn length at 2 cN/tex load after the thermal treatment is determined as (l_{g_2}). Shrinkage of yarn samples was calculated by applying the equation (2).

$$Shrinkage\ (\%) = \frac{l_{g_1} - l_{g_2}}{l_{g_1}} x100 \qquad (2)$$

In order to analyze the effect of yarn plying, bulking process velocity and temperature on knitted fabric mechanical properties such as number of wales per inch (WPI), number of courses per inch (CPI), thickness, fabric weight, air permeability, bursting strength and distention and pilling performance of the fabrics were evaluated. Single jersey knitted fabrics' thickness and weight were determined according to BS EN ISO 5084 and BS EN 12127 standards, respectively.

Air permeability of weft knitted fabrics were measured at 100 Pa test pressure drop on an area of 20 cm^2 test speed according to BS EN ISO 9237 by using SDL Atlas test device. James Heal pneumatic bursting strength tester was utilized for measuring the bursting strength and distention in accordance with BS EN ISO 13938-2 standard at 50 cm^2 test area. The pilling property was evaluated with visual assessment according to the standard ISO 12945-2 and up to 7000 rubbing cycles by Martindale Pilling Tester. After completing 7000 cycles, the samples were graded between grade 1 (severe formation of pills) and grade 5 (no or very weak formation of pills) with standard photographs under sufficient light. In order to evaluate the significance difference between ply twist, bulking temperature and bulking machine velocity parameters on yarn and knitted fabric properties, variance analysis was performed with SPSS package program at significance level of 5%. Furthermore, numerical optimization by selected yarns and knitted fabrics properties as minimum/ maximum value was evaluated by Design Expert package program.

3. RESULT AND DISCUSSION

3.1. Yarn Properties

Tensile properties of yarn samples that are tenacity and elongation were given in Figure 3. According to yarn tensile test results regarding to ply twist (tpm), bulking machine velocity (m/sec) and bulking temperature (°C), there is not a general trend for the tenacity or elongation values regarding to parameters of bulking temperature, bulking machine velocity or ply twist (Figure 3). As the bulking machine velocity (m/sec) increased, yarn samples folded at 185 tpm ply twist and exposed to bulking process at 110 °C seemed to be providing lower yarn tensile properties. When the average ply twist tenacity values are considered, the highest tenacity was found at 245 tpm yarn samples. It is an expected result that increasing twist level improves the tenacity of the yarn. Furthermore, yarn samples without bulking process reveal an increasing trend for the tenacity with the ply twist level increment as expected. Bulking process has a reduction effect on yarn tenacity as seen in Figure 3. This reduction could be due to the shrinkable fibre migrate towards the yarn centre and only about 45% of fibres support the tensile forces, the remaining 55% of the non-shrinkable fibres are buckled and appear on the yarn surface and therefore initially remain relatively untensioned [5,24]. Another reason for the lower tenacity of acrylic yarns treated to bulking process may be caused from their lower inter fibre cohesion within their yarn structure. Non-uniform fibre slippage in the cross section may lead a decrement in yarn tenacity with the bulking process [25].

Similar to yarn tenacity, the elongation values of the yarn samples without bulking process increased gradually from 185 to 245 tpm ply twist. It may be due to the increasing of fibre slippage or reduction of fibre-to-fibre friction [5]. As indicated in Figure 3(b), yarn samples without bulking process indicate lower elongation than their counterparts of treated with bulking process at each ply twist level. When bulking process is taken into consideration the stable changes are seen at 130 °C bulking temperature compared with 110 °C. The maximum elongation value was obtained from yarn sample with 245 tpm ply twist at 130 °C bulking temperature and 650 m/sec bulking machine velocity. With the increment of ply twist level, yarn samples' elongation generally seems to be increasing except those folded with 185 tpm ply twist and treated with 110 °C bulking temperature. In general, increment of the bulking temperature affects yarn elongation positively except yarn samples processed with 550 and 650 m/sec bulking machine velocity at 130 °C. However, the change in elongation may be influenced by the yarn crimp features. Because bulking process increases the voluminosity thus crimp of the yarn [6].

Crimp contraction is referred to as the crimp rigidity [26]. It can be described as the crimp potential of a textile fibre/yarn as its ability to elongate under tension. Figure 4 indicates yarn crimp contraction properties of yarn samples.

When the crimp contraction was considered, the results did not vary between each other prominently when the two bulking temperature were taken into consideration. A gradual decrement was observed among the acrylic yarns folded at 185 ply twist and processed at bulking temperature of 110 °C and among the acrylic yarns folded at 245 ply twist and treated at bulking temperature of 130°C. There is not a prominent trend for the crimp contraction of yarn samples folded with the ply twist intervals of 185 tpm and 245 tpm. This result may be attributed to high CV (%) values of ply twist resulting with lower effect to the crimp contraction.

Untreated yarns of 40% unrelax acrylic fibre groups provided higher crimp contraction (CC%) compared to those with exposed to bulking process as expected. It is understood that bulking process improved crimp contraction (CC%) results.

Figure 5 indicates the yarn shrinkage (%) values of the acrylic yarns. Except the folded yarns at 245 ply twist, processed at 130°C bulking temperature, most of the yarn samples revealed lower than 2% shrinkage level which is an acceptable result for the commercial use.

Gradual decrement with the bulking machine velocity was observed among the yarn samples folded at 185, 215 and 245 tpm ply twist processed at bulking temperature of 110 °C and among the yarn samples folded at 215 tpm ply twist processes at bulking temperature of 130°C. As an expected results untreated yarn samples shrinkage values were found to be higher than that of the shrinkage values of yarn samples treated with bulking process. Shrinkage values of untreated yarns revealed similar results between each other for each ply twist.

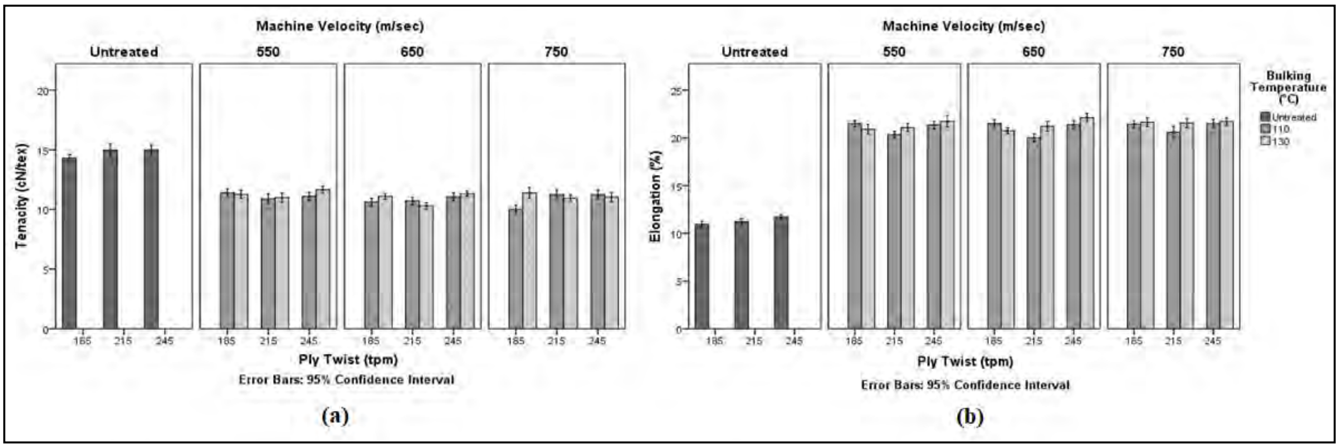


Figure 3. Yarn properties (a): Tenacity (cN/tex), (b): Elongation (%)

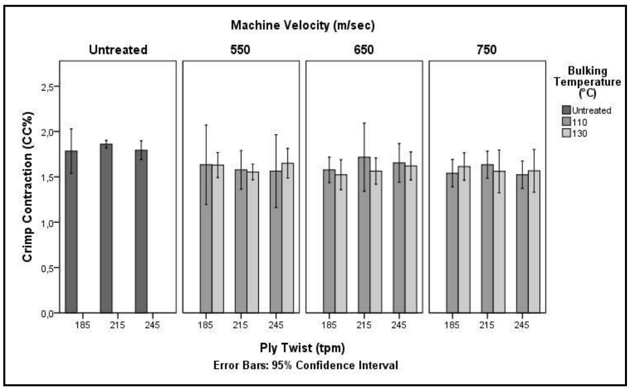


Figure 4. Yarn crimp contraction (CC%)

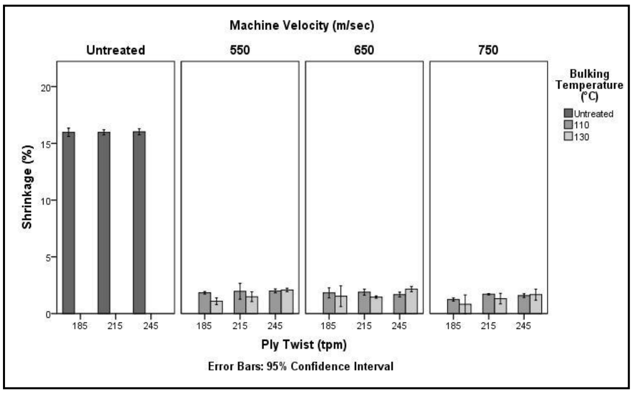


Figure 5. Yarn shrinkage (%)

According to the ply twist level in all bulking temperature and bulking machine velocity; the highest yarn shrinkage was obtained from the fabrics made of 245 tpm ply twist whereas the lowest value was found among the fabrics made of 185 ply twist. This result may be attributed to twist effect intercepting the yarn mobility for the yarn shrinkage. On the manner of bulking velocity; highest yarn shrinkage (%) was obtained from the knitted fabrics made of acrylic yarns exposed to bulking velocity of 550 and 650 m/sec whilst the lowest value was found among the fabrics made of those from exposed to 750 m/sec.

Three-direction ANOVA test was conducted for the yarn samples' mechanical properties at significance level of 0.05. Table 2 indicates the variance analysis results of untreated and treated with bulking process of yarn samples properties. As seen in Table 2, all parameters inspected have statistically significance effect on yarn shrinkage. Ply twist had significant effect on yarn tenacity and elongation. When the interaction of the factors are considered, the interaction of ply twist and bulking temperature, ply twist and bulking machine velocity, bulking temperature and bulking machine velocity were significant factors on yarn shrinkage.

3.2. Fabric Properties

Weft knitted fabric properties are given in Table 3. According to Figure 6, bursting strength of the acrylic fabrics with the yarns which did not expose to bulking process revealed higher bursting strength values when compared to others. As seen in Table 3, the fabric stitch length of untreated fabrics are higher than that of treated ones, it can be said that this situation leads to obtaining higher bursting strength. The other knitted fabrics made of acrylic yarns at different ply twists treated to different range of bulking parameters did not vary between each other prominently. A slight increment was observed at the bursting strength of the fabrics made of 185 ply twist acrylic yarns treated to bulking velocity of 750 m/sec at bulking temperature of 130 °C. There is not a clear trend for the bursting strength values of the acrylic fabrics regarding to yarns' bulking temperature or bulking velocity. However a gradual decrement for the bursting strength was observed as the ply twist increased at the bulking velocity of 550 m/sec and at the bulking velocity of 750 m/sec. Among the untreated knitted fabrics, the highest bursting strength was obtained from the fabrics made of yarns produced at lowest ply twist level (185 tpm).

Table 2. Multivariate three direction ANOVA results for yarn and fabric properties

Source		Tenacity (cN/tex)	Elongation (%)	Crimp Contraction (CC%)	Yarn Shrinkage (%)
Main Effect	Ply Twist (P)	**0.05***	**0.00***	0.58	**0.00***
	Bulking Temperature (T)	0.84	0.45	0.55	**0.00***
	Bulking Machine Velocity (S)	0.21	0.89	0.45	**0.00***
Interaction	P*T	0.73	0.25	0.16	**0.00***
	P*S	0.90	0.91	0.22	**0.01***
	T*S	0.48	0.59	0.18	**0.02***
	P*T*S	0.39	0.77	0.91	0.43

*statistically important according to α=0.05, **NOTE:** The different letters next to the counts indicate that they are significantly different from each other at a significance level of 5 %.

Table 3. Physical properties of weft knitted fabrics

Number	Ply Twist (tpm)	Bulking Temperature (°C)	Bulking Machine Velocity (m/s)	Thickness (mm)	Weight (g/m^2)	Wales/cm	Courses/cm	Stitch Length (cm)
1	185	Untreated		0.892	146.397	7	6	0.705
2	215			0.910	139.647	7	6	0.710
3	245			0.900	149.893	7	6	0.715
4	185	110	550	1.310	196.947	7	6	0.650
5	185	110	650	1.252	188.430	7	6	0.660
6	185	110	750	1.348	190.650	7	6	0.650
7	215	110	550	1.302	203.437	8	6	0.650
8	215	110	650	1.298	189.427	8	6	0.650
9	215	110	750	1.296	162.040	8	6	0.650
10	245	110	550	1.274	188.227	8	6	0.650
11	245	110	650	1.284	189.403	8	6	0.650
12	245	110	750	1.326	197.683	8	6	0.650
13	185	130	550	1.282	195.303	7	6	0.650
14	185	130	650	1.310	190.000	7	6	0.650
15	185	130	750	1.304	201.733	7	6	0.650
16	215	130	550	1.308	196.767	8	6	0.650
17	215	130	650	1.336	195.847	8	6	0.650
18	215	130	750	1.292	194.287	8	6	0.660
19	245	130	550	1.308	193.247	8	6	0.660
20	245	130	650	1.288	192.100	8	6	0.650
21	245	130	750	1.300	192.100	8	6	0.650

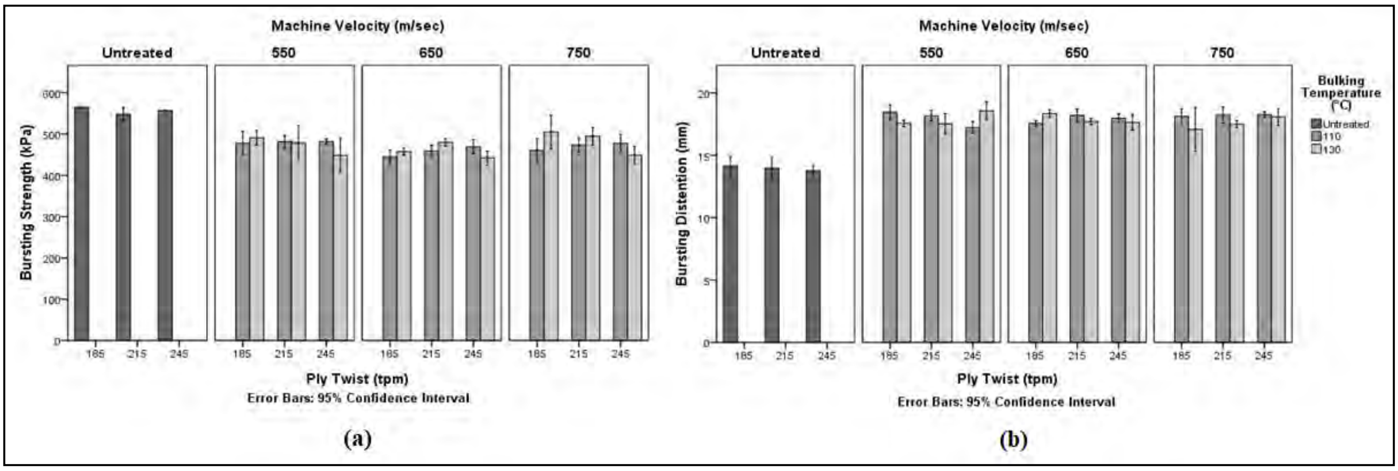


Figure 6. Weft knitted fabric properties (a): Bursting strength (kPa), (b): Bursting distention (mm)

Considering bursting distension (mm); untreated samples generally indicated lower bursting distention (mm) compared to those treated to bulking process. Among the ply twist from 185 to 245 tpm, it was observed that bursting distention decreases.

Acrylic fabrics made of 185 and 215 ply twist acrylic yarns treated to bulking temperature of 110° C revealed higher bursting distension compared to those treated to bulking temperature of 130° C among the fabric groups of acrylic yarns exposed to bulking velocity of 550 and 750 m/sec. Bursting distension of fabric groups made of 185 ply twist yarns exposed to 130 °C was prominently lower compared to other samples.

Figure 7 reveals the acrylic knitted fabrics' air permeability properties. Air permeability of the knitted fabrics made of untreated acrylic yarns indicated higher air permeability. Also untreated fabrics have lower weight with higher stitch length. This result may be attributed to non-bulked yarns' leading to fabrics with higher porosity which permits higher air transport.

When Table 3 is analysed it is also observed that those first three samples with untreated acrylic yarns have lower thickness, fabric weight but higher air permeability values compared to others Prakash and Ramakrishnan' s study also supported our result where they declared that The lower thickness and mass per square meter facilitated the passage of air through the fabric [27].

Fabrics made of yarns with higher twist level are generally expected to have higher air permeability. Higher twist leads to more compact yarns, thereby reducing intra-yarn space, and also increasing the inter-yarn spacing in the fabric. In other words, higher twist provides less dense fabrics resulting in higher air permeability. As the yarn twist increases the surface porosity of the fabric will increase resulting with high air permeability values.

It is observed that at the bulking machine velocity of 550 m/sec, air permeability values increased as the ply twist increased. However in other fabric groups with the yarns at bulking machine velocity of 650 m/sec and at 750 m/sec, there is not a general trend for the air permeability of the acrylic fabrics regarding to ply twist. This situation may be attributed to the fact that bulking parameters suppressed the influence of ply twist effect on air permeability of the acrylic fabrics.

Three-direction ANOVA test (Table 4) was conducted for the fabric samples' mechanical properties at significance level of 0.05. Bulking machine velocity (S) had significant effect on bursting strength (kPa) at significance level of 0.05. The interaction of ply twist and bulking temperature (P*T) was a significant factor on air permeability, bursting strength and bursting distension respectively. The interaction of bulking speed bulking temperature and ply twist (P*T*S) was also significant on bursting distension (mm) at significance level of 0.05.

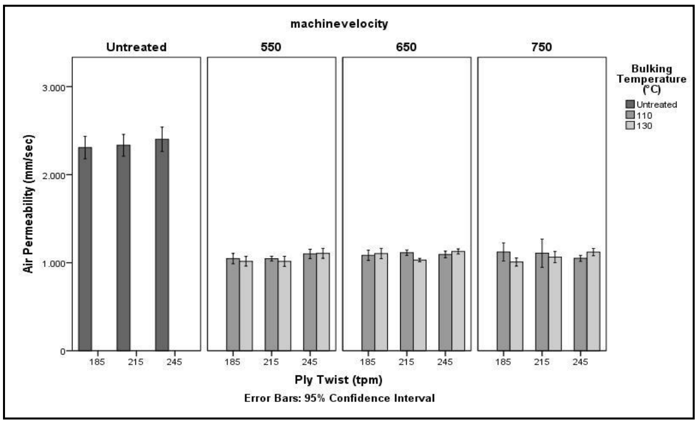


Figure 7. Weft knitted fabrics air permeability (mm/sec)

3.3. Pilling Properties

Pilling properties of weft knitted fabrics after 7000 rubbing cycles were evaluated and graded with standard photographs under sufficient light and results were given in Table 5. It is seen that fabrics from untreated yarns at different ply twist have lowest pilling grade that is severe formation of pills. By determining with visual comparing it was seen that there was no difference between fabrics pilling grade of fabrics produced at different ply twist, bulking temperature and bulking machine velocity parameters.

In the yarn structure, increasing the inter-fibre friction due to bulking process could lead to increase fiber-to fiber cohesion. Thus knitted fabrics produced from these yarns will be more resistant to pill under the influence of friction force.

Table 5. Pilling properties of weft knitted fabrics

Number	Ply Twist (tpm)	Bulking Temperature (°C)	Bulking Velocity (m/s)	Pilling Grade
1	185	Untreated		1-2
2	215			1-2
3	245			1-2
4	185	110	550	2-3
5	185	110	650	2-3
6	185	110	750	2-3
7	215	110	550	2-3
8	215	110	650	2-3
9	215	110	750	2-3
10	245	110	550	2-3
11	245	110	650	2-3
12	245	110	750	2-3
13	185	130	550	2-3
14	185	130	650	2-3
15	185	130	750	2-3
16	215	130	550	2-3
17	215	130	650	2-3
18	215	130	750	2-3
19	245	130	550	2-3
20	245	130	650	2-3
21	245	130	750	2-3

3.4 Optimization

In order to determine the best desirability functions by using numerical optimization technique, both yarn and weft knitted fabric properties inspected in this study were included into the analysis. For this purpose, untreated yarn and weft knitted fabric samples were excluded for determining of final product desirability function. Thus, 18 types of yarns and weft knitted fabrics properties; yarn tenacity, yarn elongation, yarn crimp contraction, yarn shrinkage, fabric bursting strength, bursting distention and air permeability properties; were analyzed. Numerical optimization technique was used to determine how well the specified goals are achieved. As some researchers prefer, Design Expert package program was selected to perform numerical optimization technique [29-30].

Before conducting numerical optimization, parameters range should be defined as "is in range", "target value", "maximize" or "minimize" according to independent parameters and response variables to be evaluated. The constraints for the optimization process of ply twist, bulking temperature, bulking machine velocity and response variables are given in Table 6. Here, independent parameters such as ply twist, bulking temperature and bulking machine velocity were taken as "is in range". Each examined parameters and response variables of yarn and knit quality properties, the acceptance interval of lower and upper limits for each property was designed according the consumer requirements for winter use.

Response variables to be analysed were taken either "maximize" or "minimize" according to the yarns and weft knitted fabrics expectation properties for final product usage. The desired goal of response variables such as yarn tenacity, yarn elongation, crimp contraction was taken as "Maximize" and shrinkage was taken as "Minimize". Besides, desired goal of weft knitted fabric properties as bursting strength, bursting distention were taken as "Maximize" and air permeability was taken as "Minimize".

For various responses and factors, all targets were combined as a desirability function which changes from 0 (least desirable) to 1 (most desirable) [28]. Desirability function includes use of a geometric mean of individual desirability and represents "Overall Desirability" [29]. Another important function for numerical optimization is to define the importance of each independent parameters and response variables. The importance of variables can vary from least important (+) to the most important (+++++). In this study, all independent parameters and response variables were taken the (+++) importance. Table 6 indicates the results of numerical optimization and desirability. Also, optimum ply twist, bulking temperature and bulking machine velocity are exhibited in Table 7.

Table 4. Multivariate three direction ANOVA results for yarn and fabric properties

Source		Air Permeability (mm/sec)	Bursting Strength (kPa)	Bursting Distention (mm)
Main Effect	Ply Twist (P)	0.72	0.18	0.59
	Bulking Temperature (T)	0.13	0.68	0.25
	Bulking Machine Velocity (S)	0.15	**0.01***	0.82
Interaction	P*T	**0.04***	**0.00***	**0.03***
	P*S	0.71	0.31	0.23
	T*S	0.45	0.34	0.06
	P*T*S	0.15	0.44	**0.01***

*statistically important according to α=0.05, **NOTE:** The different letters next to the counts indicate that they are significantly different from each other at a significance level of 5 %.

Table 6. Constraints for the optimization process of ply twist, bulking temperature, bulking machine velocity and response variables

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Ply twist (tpm)	is in range	185	245	1	1	3
Bulking temperature (^oC)	is in range	110	130	1	1	3
Bulking machine velocity (m/sec)	is in range	550	750	1	1	3
Tenacity (cN/tex)	maximize	10.0135	11.658	1	1	3
Elongation (%)	maximize	20.0147	22.1165	1	1	3
Crimp contraction (CC%)	maximize	1.52333	1.71667	1	1	3
Shrinkage (%)	minimize	0.82	2.15	1	1	3
Bursting Strength (kPa)	maximize	442.24	505.2	1	1	3
Bursting distention (mm)	maximize	17.08	18.56	1	1	3
Air permeability (mm/sec)	minimize	1007.6	1128	1	1	3

Table 7. Results of desirability functions

Number	1	2	3	4	5	6	7
Ply twist (tpm)	185.00	185.00	185.00	186.38	185.00	185.92	189.55
Bulking temperature (^oC)	130.00	130.00	130.00	130.00	130.00	130.00	129.83
Bulking machine velocity (m/sec)	613.72	614.48	631.32	613.87	560.46	550.48	714.75
Tenacity (cN/tex)	11.1392	11.1378	11.107	11.1392	11.2365	11.2531	10.9673
Elongation (%)	20.94	20.942	20.9865	20.959	20.7993	20.7867	21.2566
Crimp contraction (CC%)	1.58004	1.57993	1.57759	1.58058	1.58744	1.58923	1.56785
Shrinkage (%)	1.33802	1.33669	1.30722	1.34861	1.43123	1.45592	1.19898
Bursting strength (kPa)	1019.94	1020.11	1023.81	1021.93	1008.24	1007.6	1047.07
Bursting distention (mm)	489.051	489.09	489.96	488.182	486.3	485.202	491.104
Air permeability (mm/sec)	17.9	17.9	17.9	17.9	17.9	17.9	17.9
Overall desirability	0.572	0.572	0.571	0.570	0.568	0.566	0.555

As clearly seen in Table 7, the highest overall desirability (Number 1) with 0.57 value can met the goal if yarn sample produced at 185 tpm ply twist, 130 °C bulking temperature and 614 m/sec bulking machine velocity. In other words, it can be said that yarn produced at low ply twist, low bulking machine velocity and high bulking temperature are suitable for achieving the desired goals. It can be said that desirability function is high, however, it is hard to say meeting the all yarn and knitted fabric properties goal with the level of ply twist, bulking temperature and bulking machine velocity used in this study.

Moreover, optimized yarn and knitted fabric properties were also given in Table 7 as a result of the numerical optimization technique. Among the all overall desirability values, the least desirability was obtained approximately 0.56 can met the goal if yarn sample produced at 190 tpm ply twist, 130 °C bulking temperature and 715 m/sec bulking machine velocity. Although the difference between lowest and highest desirability values is similar, this result shows that yarns should not be produced at higher bulking machine velocity at higher ply twist. And also, bulking temperature should be avoided at higher.

4. CONCLUSION

The aim of this study was built on the evaluation for the effect of ply twist, bulking temperature and bulking machine velocity on tensile and elongation properties of folded acrylic yarns as well as on bursting strength, bursting distension and air permeability (mm/sec) of knitted fabrics made of those yarns. Additionally, main objective of this work was to investigate the coincident optimization of all yarns and fabrics properties based on Numerical Optimization Method.

As a general conclusion; untreated yarn samples without bulking process indicated higher yarn tenacity, crimp contraction, shrinkage (%) but lower yarn elongation (%). Ply twist was a significant factor on yarn tenacity and on elongation (%). Ply twist, bulking temperature, bulking velocity and their binary interaction had significant effect on yarn shrinkage (%). However interaction of ply twist, bulking temperature and bulking machine was an insignificant factor for yarn shrinkage (%). Regarding to fabric properties; bulking machine velocity had significant effect on bursting strength (kPa) at significance level of 0.05. The interaction of ply twist and bulking temperature was a significant factor on air permeability, bursting strength and bursting distension respectively. The interaction of bulking speed bulking temperature and ply twist (P*T*S) was only significant on bursting distension (mm) at significance level of 0.05. Except the fabric samples of untreated yarns , air permeability and bursting strength, bursting distension of fabrics made of acrylic yarns at different ply twist, different bulking velocity, bulking temperature did not vary between each other prominently.

According to optimization results; the best overall desirability was obtained at lowest ply twist and bulking machine velocity with highest bulking temperature to meet the desired yarn and knitted fabric properties. Moreover, this technique can be used to predict the acrylic knitted fabric quality according to the customer needs. For the further study, the extended fiber properties including relax/unrelax acrylic fiber ratio, fiber fineness, fiber length etc. can be optimized.

As a final conclusion; it seems that high-bulk acrylic yarns which contract and increase in bulk during the heat relaxation process will be more preferable for the knitted fabrics. Hence, it might be suggested to conduct further studies related to a whole evaluation of comfort properties of acrylic fabrics by selecting some yarn process parameters including the shrinkable and non-shrinkable acrylic ratio.

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