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Investigation of Anti-Pilling Properties of Different Fabrics Applied with Polyvinylcaprolactam

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ABSTRACT

Pilling is one of the most important problems in the textile industry still not confidently solved. The problem is a kind of mechanically caused fabric defect consisting by a series of roughly spherical masses of entangled fibers called pills. Many studies have been carried out to define this problem in detail, determine the pilling intensity by different methods and improve the pilling grades of fabrics. One of the most beneficial methods to improve values is chemical finishing by applying specific polymers. In this study, a specific synthesized anti-pilling polymer was used for chemical finishing by padding method. A specific polymer based on polyvinylcaprolactam (PVCL) was synthesized and applied on the fabrics. The polymer has been characterized with FT-IR, NMR, DSC, elemental analysis devices also to optimize application-parameters. Especially pilling grades of blended fabrics of natural and synthetic staple fibres are often worser then other non blended fabrics, PVCL polymer was applied on a selection of different polyester cotton blends or polyester viscose blend, which have pilling values between 2-3. PVCL-Polymer applications were carried out by using these 7 different fabrics. As a result, approximately 1.5-2 pilling degree improvement was achieved. Anti-pilling polymers applied on the fabrics used to improve pilling values often decrease hydrophilicity values of the fabrics and worsen touch. However, the specific PVCL-polymer does not lead to a loss of smooth hand neighter to a loss of smooth fabric touch. On the contrary, it improves both hydrophilicity and smooth touch not causing fabric yellowing. PCVL is distinguished from other products used for pilling improvement in the textile industry.

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KEYWORDS

Anti-pilling, pilling, hydrophilicity, polyvinylcaprolactam

1. INTRODUCTION

For sustainable textiles, quality must be increased in order to use the garment for a long time without losing its properties. If the clothes used are long-lasting, the user's need for new clothes decreases and the quality increased textiles can be used as second-life clothes by other consumers. In addition, the production of quality products indirectly reduces the product environmental footprint [1]. One of the most important quality problems in the textile industry which shortens the life-time of garments is pilling. Pilling is a crucial parameter for fabric's quality and sustainable textiles. Pilling is a surface defect of textiles caused by intensive wear and care of textiles, like washing and tumble drying. This problem is especially important for fabrics that appeal to the human senses, such as top clothing and upholstery [2]. Mainly, pilling is seen in garment areas near pockets and collars, so pills are mostly found in these areas [3].

A lot of parameters influence pilling in knitted and woven fabrics, like type of fibres, shape of fibres, fibre staple length, spinning technology used to produce the yarn, fabric construction, finishing technology, etc. All these parameters influence the pilling tendency of a garment [4]. Knitted fabrics tend to pill more readily than woven fabrics. Since knitted constructions are composed of a series of loops, a greater amount of yam surface area is exposed, making them more susceptible to abrasion in wear. Moreover, knitted fabrics are more often constructed of low-twist yarns made of staple fibres to give a soft, bulky feel and appearance [5].

The pilling mechanism complex and many factors affect pilling during the use of the fabric. Pilling problems may occur in addition as a result of misuse and very often wrong washing of clothes. One of the main reasons that accelerates the formation of pilling is the unnecessarily long and intensive wash cycles which increase mechanical rubbing on the fabric surface creating even more pilling.

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With the increase use of synthetic fibers and their blends in recent decades, the importance of pilling has increased even more [4]. In example polyester fabrics have excellent properties such as high strength, attractive hand, dimensional stability and easy-care properties. Out of these reasons polyester fibers are the most frequently fibres used in the textile industry including outdoor, sports and active wear, as well as protective clothing, medical textiles, automotive parts and in many other technical textile applications. However, the pilling of polyester staple fibre-fabrics and snagging of polyester filament fabrics are still not totally solved problems [7]. As the polyester content increases in e.g. polyester (PES)/cotton (CO) blend fabric, pilling almost increases [8]. Increased pilling occurs on the fabric surface because polyester acts as a kind of anchor fiber for the pill [9]. Because of polyester-fibers do not fracture easily and therefore their pills do not easily wear off [10].

To determine fabric's pilling tendency, various methods have been used and reported in literature [11-15], Martindale is the most common pilling test in textile industry. The PVCL-polymer treated fabrics were exposed to 2000 cycles by using Martindale pilling tester device according to the ISO-12945-2 method.

Some methods used to improve the pilling degrees of fabrics have been reported in the literature [17-19]. One of the most useful of these methods is chemical finish [20, 21]. Endo or exo-cellulases are generally used as an anti-pilling agent in textile finishing [22, 23]. Sufficient pilling improvement in PES/CV, PES/CO, CO/CV blended fabrics could be obtained except viscose (CV) fabrics with these chemicals. The impact of cellulose waste on cellulosic fabrics were studied by Körlü et al. Cellulase enzymes are less effective in viscose fabrics in comparison to cotton fabrics [24]. Anti-pilling compounds, in addition to enzymes, have been utilized. All of today's anti-pilling chemicals have the disadvantage of being pricey or giving fabrics a rough hand. Despite the fact that several different compounds have been claimed to be anti-pilling chemicals [25], the textile industry requires more than only anti-pilling properties. The cloth treated with anti-pilling chemicals should also have other desirable characteristics [26]. It should keep its hydrophilicity, be non-yellowing, and have a nice hand. As a result, an alternate anti-pilling chemical is needed to address the pilling issue. The anti-pilling polymer developed by the researchers in this study differs in that it minimizes the likelihood for pilling while having no negative impact on fabrics' hydrophilicity, hand, or brightness. Polyvinylcaprolactam is the name of the anti-pilling polymer that has been synthesized and studied. PVCL was applied and tested on a variety of fabrics to establish its effectiveness as an anti-pilling agent. PVCL was also tested to see if it had any detrimental effects on the fabrics' hydrophilicity and brightness. PVCL is a functional polymer that has been shown to work as an anti-pilling agent for a variety of fabrics with no negative side effects. As a result, the pilling problem in fabrics is eradicated, allowing for higher-quality products while also lowering energy, production, and operating expenses [27].

2. MATERIAL AND METHOD

2.1. Material

2.1.1 Chemicals

Vinylcaprolactam (VCL) (BASF) was used as a monomer and was supplied from BASF. 2M Azobisisobutyronitrile (AIBN) in toluene is the an initiator for polymerization of VCL. These chemicals were supplied from Merck.

2.1.2 Fabrics

In order to demonstrate the improvement of pilling values, it was purposefully worked with fabrics where improvement is hardest to achieve. For this purpose, fabrics are generally chosen from blended fabrics containing polyester and viscose fibers. The pilling value of the fabrics used should be maximum level 3 in Martindale testing to understand whether the specially modified Polyvinylcaprolactam (PVCL) improves pilling values in the fabrics. While selecting fabrics with a maximum pilling value of 3, untreated fabrics were exposed to Martindale test method. Seven fabrics with a pilling degree of 3 or less were used throughout the study, and they are listed in the Table 1 from F-1 to F-7. A microscopic approach was utilized to qualitatively determine which fibers are present in fabrics. The microscope's brand is Olympus, and the model is BX51. Following the microscopic identification of the fibers in the fabrics, their percentages in the fabrics were determined using a chemical method according to ISO-1833-11. Table 1 lists the fibers in the fabrics as well as their percentages. For F-1, PES and CO fibers were found under the light microscope. The percentages of these fibers were determined as 68% PES, 22% CO by chemical method. CV and PES fibers were observed for F-2. The percentages of these fibers were discovered to be 64% PES, 32% CV and 4% EA., F-3 consists of CV and PES fibers. The percentages of these fibers were determined as 77% CV and 23% PES. F-4 is made up of CV and PES fibers, as shown in Table 1. 78 percent CV and 22 percent PES were determined to be the percentages of these fibers. Only CO fibers were found in F-5, indicating that it is totally made up of CO textiles. Under a light microscope, PES and EL fibers were visible in F-6. By using a chemical approach, the percentages of these fibers were discovered to be 66 percent PES, 32 percent CV, and 2 percent EL. F-7 fibers were discovered to be CV, PES, and EL. The percentages of PES, CV, and EA were discovered to be 64 percent, 32 percent, and 4 percent, respectively. Fabric surfaces were photographed at x44 magnification using a digital surface microscope (LEICA brand, DVM6 model). Table 1 contains images.

Table 1. Properties of fabrics

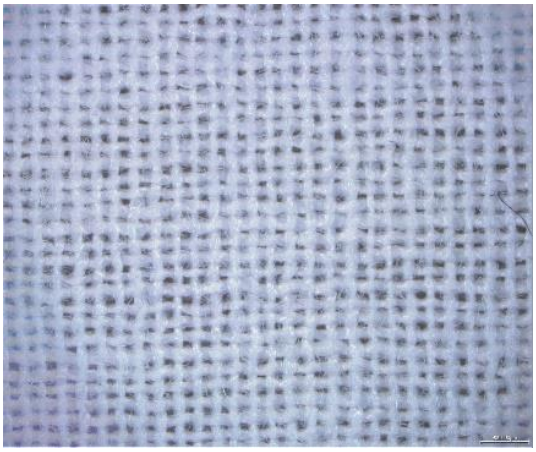
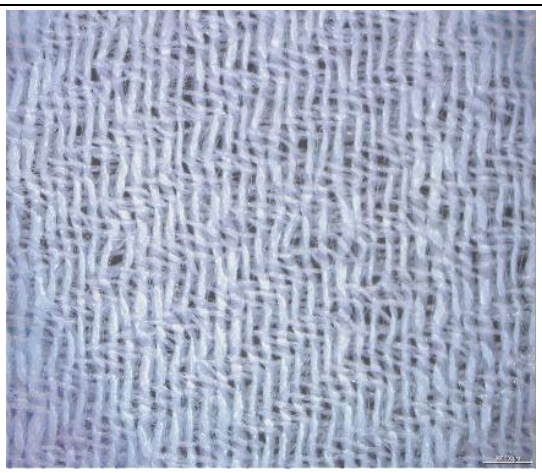
Article	Colour	Fabric type	Fiber composition	Surface image of fabric under digital surface microscope
F-1	White	Woven	68% PES, 32% CO	
F-2	White	Woven	55% CV, 45% PES	
F-3	light pink	Woven	77% CV, 23 % PES	
F-4	dark pink	Woven	78% CV, 22 % PES	

Table 1. Continued

Article	Colour	Fabric type	Fiber composition	Surface image of fabric under digital surface microscope
F-5	Orange	Knitted	100% CO	
F-6	green plaid pattern	Woven	66% PES, 32% CV, 2% EA	
F-7	Black	Woven	64% PES, 32% CV, 4% EA	

2.2 Method

2.2.1 Synthesis of PVCL

Vinylcaprolactam (VCL) and the initiator 2 M AIBN in toluene were used for synthesis. PVCL was synthesized by free radical polymerization method [28,29]. 50 ml of VCL (0.37 mmol) and 3.25 g of 2 M AIBN in toluene (0.017 mmol) were added. Reaction was carried out at 65 °C under nitrogen atmosphere. The reaction was completed after 3 hours, PVCL was obtained as slight yellowish liquid. The chemical structure of the VCL monomer (Figure 1) and reaction scheme (Figure 2) are given below.

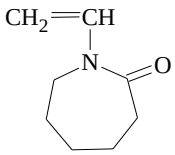


Figure 1. Structure of VCL

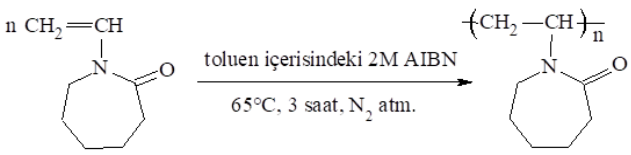


Figure 2. Polymerization reaction of PVCL

2.2.2 Polymer Characterization

PVCL was characterized by FT-IR (Shimadzu, IR-Prestige-21), NMR (JEOL-ECZ500R), UV-Visible Spectrophotometer (Shimadzu, UV-1700, PharmaSpec), DSC (Perkin–Elmer DSC 4000 equipment), and elemental analysis (Perkin Elmer 2400 Series II).

2.2.3 Finishing process

Continous impregantion by padding method was used for the application process. PVCL solutions with concentrations of 10, 20, 30, 40 and 50 g/l were prepared by using soft water adjusted to pH value 5.5 by using acetic acid. These solutions applied to fabrics using the padding method. The foulard machine used in the applications is made by Ataç and is type F-350. The fabrics were then dried on the Mathis-stenter frame at 130°C after this process (Mathis brand, PTC 96 model). PVCL was applied on white treated fabric to observe the yellowing impact. Fabric was subjected to 170°C after the application process. By impregnating the seven different reference fabrics at individual squeeze roller pressures of 2-3 bar to obtain a pick-up value on of 70% on all fabrics was achieved. The fabrics were dried at different temperatures on the Mathis-stenter frame. In order to define the optimum temperature for PVCL, the temperature range during drying of the fabrics was studied with different temperature values between 120°C and 170°C. In addition, 170°C was used to understand the yellowing effect of PVCL on white fabrics by Datacolor degree of whiteness detection method. Parallel studies were carried out for all fabrics, first for the touch and hydrophilicity and the second for the pilling test.

2.2.4 Measuring pilling values of fabrics treated with PVCL

Martindale pilling tester device was used to determine pilling values of the fabrics. PVCL treated fabrics were exposed to 2000 cycles by this device according to the ISO-12945-2 method.

2.2.5 Determination of pilling values of fabrics treated with PVCL

The pilling potential of treated fabrics was predicted using a subjective method. PVCL-treated fabrics achieved a perfect score of 5 out of 5. There will be no piling in the fabric as a result of this. A score of 4 indicates very minimal pilling, whereas a score of 3 indicates moderate pilling. Pilling is plainly noticeable in a fabric with a pilling score of 2. Fabrics with a lot of pilling get a score of 1.

2.2.6 Determination of hydrophilicity values of fabrics treated with PVCL

The water absorption capacity of the fabrics is examined when obtaining their hydrophilicity values. The AATC 79 standard procedure is utilized for this. A stopwatch is used to measure time in this method. The stopwatch begins when water is sprayed onto the fabric with a pipette and ends when the fabric absorbs the water drop. The fabric's hydrophilicity value is calculated using the elapsed time. This method was used to measure the hydrophilicity of all treated textiles. As a result, the influence of anti-pilling chemicals on the fabric's water absorbency values was evaluated.

2.2.7 Evaluation of hand of fabrics treated with PVCL

The hand of PVCL-treated fabrics was compared to that of untreated materials. As a result, the impact of anti-pilling polymer on fabric hand was explored. The hand is assessed based on the sensation it gives the user as they take the fabric between their fingertips. The cloth might be described as silky, slippery, thick, or thin as a result of this sensation. The favored hand is usually the same, despite the fact that the hand is relative and varies from person to person from time to time. When the treated fabrics' hand was compared to their untreated counterparts, the hand effect of PVCL was found to be identical.

2.2.8 Evaluation of whiteness values of fabrics treated with PVCL

The whiteness test was carried out with the Datacolor 600TM equipment. White cloth was treated with 50 g/l PVCL to evaluate the yellowing effect of PVCL on treated fabrics. In a Mathis-stenter frame, the fabric was exposed to 170°C for 1 minute after application. Using a Datacolor equipment, the whiteness value of this cloth was measured in Berger units. In the Berger unit, the whiteness value of the untreated fabric was also assessed. Untreated cloth and fabric treated with 50 g/l PVCL had their whiteness values compared.

3. RESULTS AND DISCUSSION

N-vinylcaprolactam was polymerized by free radical polymerization. 2 M AIBN in toluene was used as a cataylst and VCL was used as a monomer. Therefore, PVCL was synthesized successfully.

3.1 Determination of polymerization with FT-IR analysis

The FT-IR spectra of VCL and PVCL are given in Figure 3 and Figure 4. Their spectrums are compared in Figure 5. Also, the peak assignments are tabulated in Table 2. Firstly, FT-IR spectrum of VCL is observed and it is shown in the following figure.

In the FT-IR spectrum of VCL, the characteristic carbonyl peak (C=O) is at 1622 cm^{-1}. The peaks for the C=C were observed at 1661 cm^{-1} and at 943 cm^{-1}. The peaks in the 2932 and 2851 cm^{-1} correspond to the aliphatic C-H stretching. The -CH_2- peaks are at 1439–1305 cm^{-1}. C-N stretching vibrations are at 1266–1046 cm^{-1}.

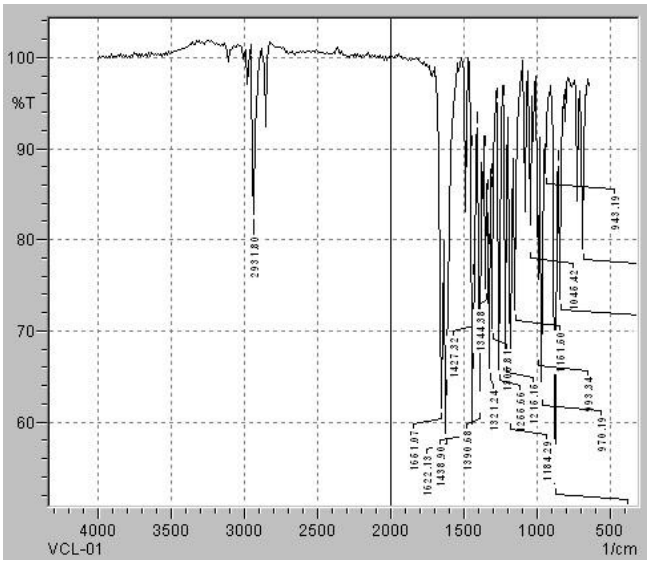


Figure 3. FT-IR spectrum for VCL

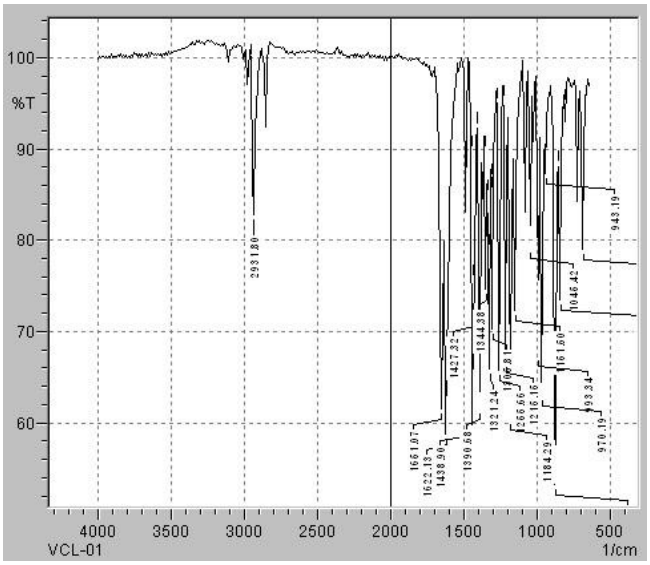


Figure 4. FT-IR spectrum for PVCL

In the spectrum of PVCL, C=O bond stretching at 1622 cm^{-1} becomes broader and peak of double bond (-C=C-) near C=O peak disappeared. The aliphatic C-H stretching was observed at 2924 and 2865 cm^{-1}. The vinyl, CH_2=CH- peak in the spectrum of monomer at 943 cm^{-1} is not observed in the spectrum of PVCL. The other vinyl peak at 1622 cm^{-1} is replaced with shifted C=O peak. The CH_2 peaks are at about 1440 cm^{-1}. Peaks belong to double bond disappeared completely. The peaks of C-N stretching vibration at 1261–1161 cm^{-1} in the monomer spectrum showed changes in intensity and position in the spectrum of polymer. This might be due to changes in conformation of side group and resonance structures. This can also be observed in the range of 3700–3150 cm^{-1} where new peaks corresponding to the OH and N-H are observed in the spectrum of polymer. The sharpness of the peaks in polymer spectrum showed regularity in polymer molecular chain.

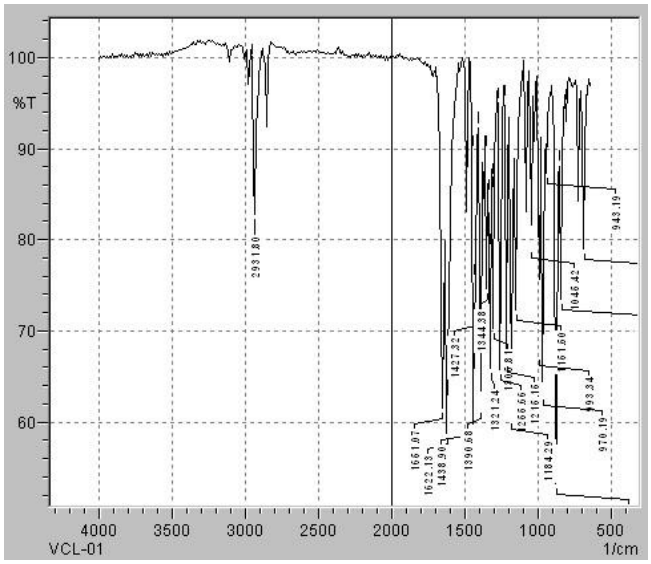


Figure 5. FT-IR spectrum for VCL and PVCL samples

FT-IR spectra of monomer and polymer is compared and it is proved that polymer was successfully obtained and the polymerization proceeds by carbon-carbon double bond opening. Shift values of monomer and polymer are given below.

Table 2. Shift values of VCL and PVCL

Functional group	VCL, shift (cm^{-1})	PVCL shift (cm^{-1})
N-H	3150	3150
Aliphatic C-H	2924, 2864	2924, 2864
C=O	1622	1622
C-N	1477	1477
-CH_2	1440	1440
C=C	1661	-
=CH and CH_2	2924, 943	-
O-H	-	3450

These results are very similar to those reported in the literature [30]. The FT-IR spectrum of PVCL, with results consistent with the literature, clearly showed that the polymer was successfully synthesized.

3.2 Determination of polymerization with NMR analysis

H atoms in PVCL structure are numbered and illustrated in Figure 6. In the ^{1}H-NMR spectrum of PVCL, four different peaks were observed.

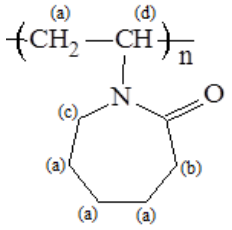


Figure 6. Numbered representation of H atoms in PVCL structure

The ^{1}H NMR spectrum of the polymer is provided in Figure 7. ^{1}H-NMR spectrum of PVCL taken in DMSO-d6 is examined, peaks are obtained as below. In the ^{1}H-NMR spectrum, the protons (H_a) for methylene group, (6 H, -CH2- of the caprolactam ring and 2H, −CH2− of the backbone) appear at 1.524 ppm. The peaks for CH2 groups close to C=O (2H, −COCH2−), (H_b) are observed at 2.293 ppm and the peaks for −CH2 groups close to N (2H,−NCH2−), (H_c) are seen at 3.040 ppm. The peaks for CH group (^{1}H,−NCH−of the α position), (H_d) are exhibited at 4.341 ppm.

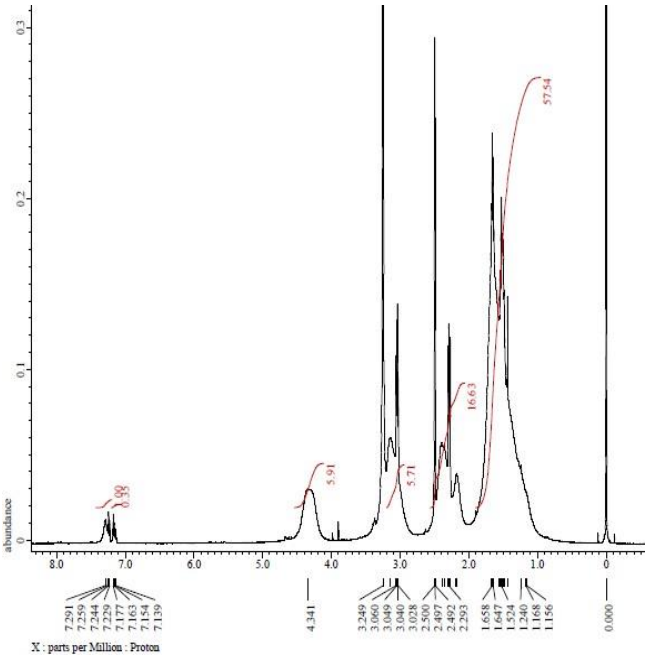


Figure 7. NMR spectrum for PVCL

These characteristic peaks are similar to articles reported in the literature [31]. Thus, it has been proved that homopolymerization takes place and PVCL is successfully synthesized.

3.3 Determination of polymerization with differential scanning calorimetry (DSC) analysis

By using Perkin–Elmer DSC 4000 equipment, differential scanning calorimetry was performed. Measurements were taken by using 3 mg PVCL sample. The DSC thermogram of the polymer are given in Figure 8. In the thermogram of the polymer, there is a broad peak at about 67°C and a less probable peak at about 137°C, which can be the glass transition temperature (T_g) value.

Values are similar to results reported in the literature [30]. Hence, it is proven that PVCL was synthesized in success.

3.4 Determination of polymerization with elemental analysis

Elemental analysis results of PVCL are given in Table 3.

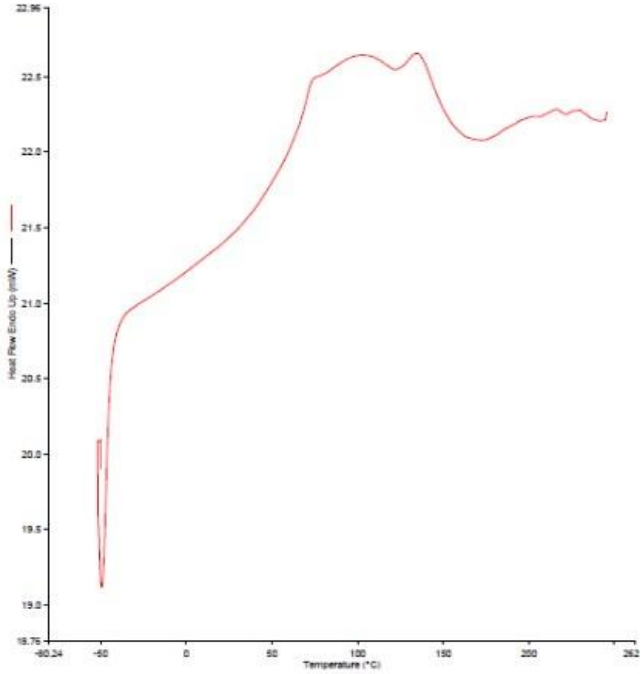


Figure 8. DSC results for PVCL

Table 3. Elemental analysis results of PVCL

Composition of the initial reaction mixture (mol%)		Elemental analysis (%)		
VCL	2 M AIBN in toluene	Carbon	Hydrogen	Nitrogen
95.61	4.39	65.39	9.37	10.09

3.5 The impact of the polymer on pilling efficiency

Foulard process was applied to fabrics (F1 to F7) with PCVL polymer synthesized and characterized. Pilling performance of treated fabrics which dried in the stenter machine and rested in condition was tested with the Martindale pilling device. Pilling values of the fabrics were determined with the subjective method and pillgrade machine. The data obtained are given in the Table 4. As can be seen from table, when the pilling values of untreated fabrics are between 2 and 3, treated fabrics have better pilling values. Also improvement of the values are higher when application quantity of PVCL increases.

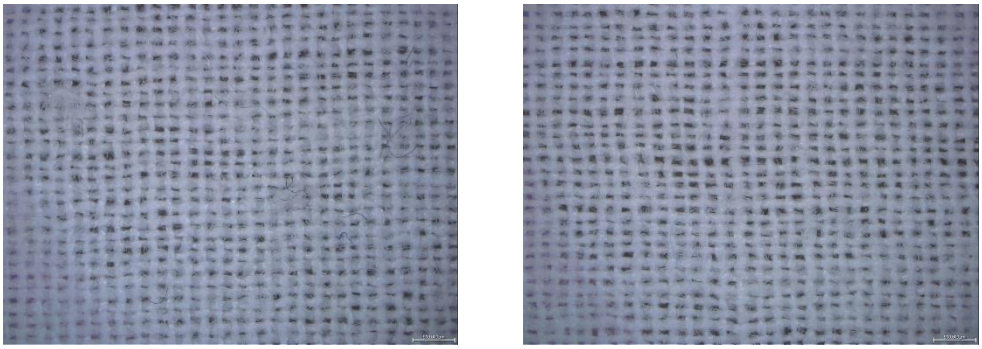
It is clearly demonstrated that PVCL contributes anti-pilling properties of fabrics. 40 g/l PVCL application is enough for all fabrics in order to achieve acceptable pilling degrees. It is obsersed that nearly 1.5 pilling grades of improvement was achieved after 40 g/l PCVL application.

Surface images of PVCL treated (40 g/l) and untreated fabrics after the pilling test were also compared to demonstrate PVCL decreases pilling tendency of the fabrics. Photographs including the surface images of the fabrics are shown in Figure: 9-15. There are almost no pills on the surface of all treated fabrics with 40 g/l PVCL when a lot of pills are seen on the surface of untreated ones.

Table 4. Pilling results of fabrics treated with different concentrations of PVCL

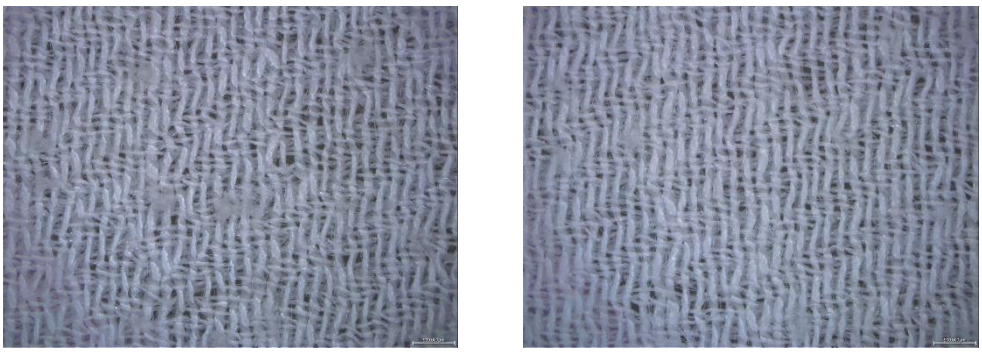
Artical	Pilling degrees of untreated fabric	Pilling degrees of treated fabric with 20 g/l PVCL	Pilling degrees of treated fabric with 30 g/l PVCL	Pilling degrees of treated fabric with 40 g/l PVCL	Pilling degrees of treated fabric with 50 g/l PVCL
F-1	3	4	4-4.5	4-5	4.5-5
F-2	3	3.5-4	3.5-4	4	4
F-3	2	2.5-3	2.5-3	3	3-3.5
F-4	2-3	3	3	3-4	3.5-4
F-5	2-3	3	3	3.5	3.5
F-6	3	4-4.5	4.5	4.5-5	4.5-5
F-7	2-3	3.5	4	4.5-5	4.5-5

*Degree of pilling 5: means no pilling; 1 means very severe pilling



A **B**

Figure 9. Surface images of F-1 **A)** Untreated **B)** 40 g/l PVCL treated

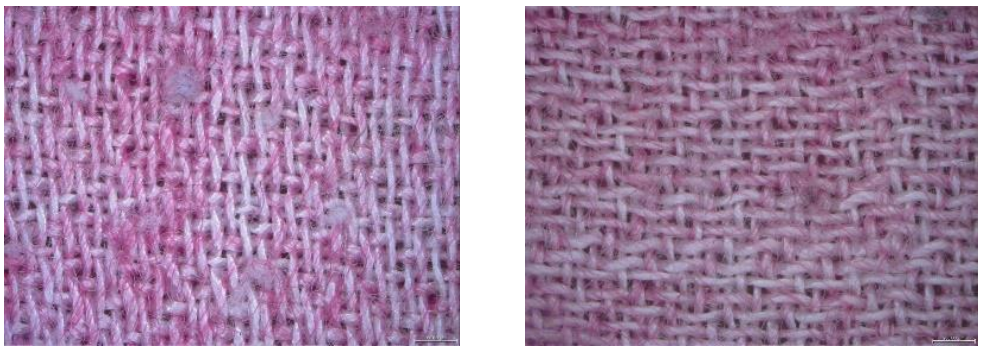


A **B**

Figure 10. Surface images of F-2 **A)** Untreated **B)** 40 g/l PVCL treated

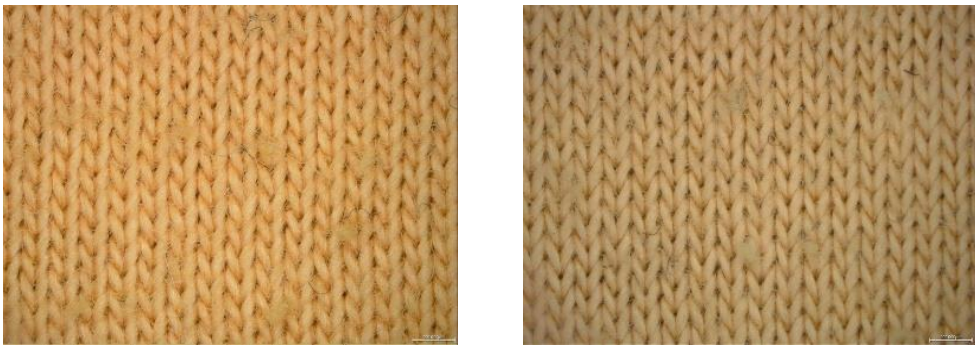
A **B**

Figure 11. Surface images of F-3 **A)** Untreated **B)** 40 g/l PVCL treated



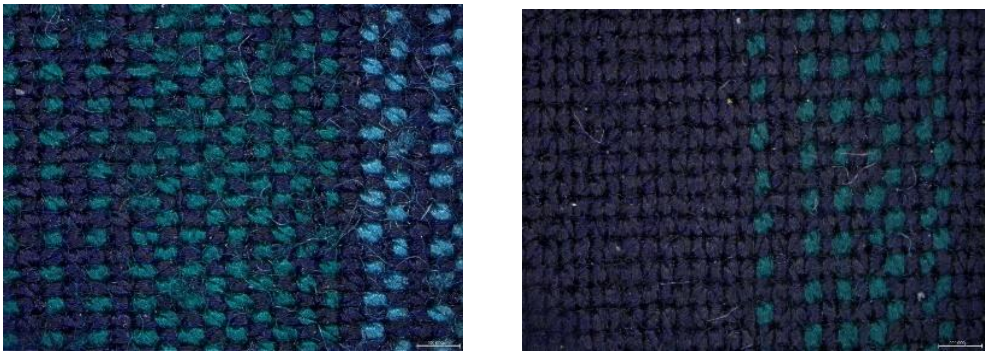
A **B**

Figure 12. Surface images of F-4 **A)** Untreated **B)** 40 g/l PVCL treated



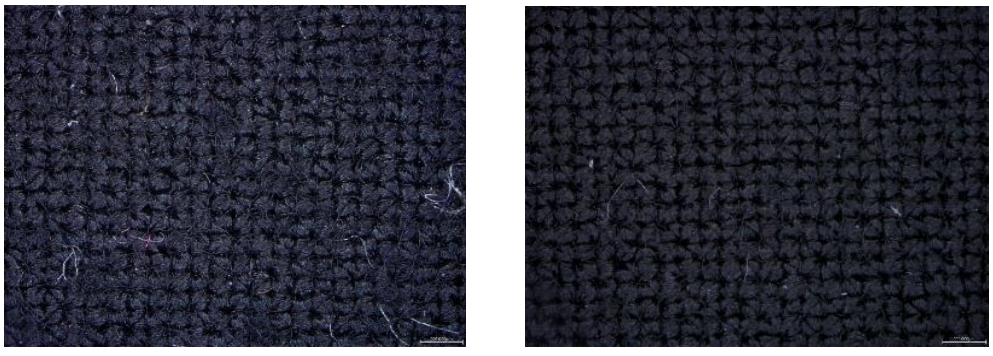
A **B**

Figure 13. Surface images of F-5 **A)** Untreated **B)** 40 g/l PVCL treated



A **B**

Figure 14. Surface images of F-6 **A)** Untreated **B)** 40 g/l PVCL treated



A **B**

Figure 15. Surface images of F-7 **A)** Untreated **B)** 40 g/l PVCL treated

3.6 The impact of polymer on fabric hydrophilicity

Hydrophilicity values of untreated and PVCL-treated fabrics were demonstrated in Table 5. Hydrophilicity of F-1 and F-7 untreated fabrics was not good enough and their values were recorded as 10 and 50 second. When PVCL applied to these fabrics their hydrophilicity values were measured as 1 second, means they absorbs water immediately. For other treated fabrics, hydrophilicity values were recorded better than untreated ones or remains same if they absorbs water in 1 second. In short, it is clearly demonstrated that PVCL contributes hydrophilicity.

3.7 The impact of polymer on fabrics hand

A hand with a rating of 5 out of 5 is very soft, while one with a value of 1 is quite hard. Fabrics that have not been treated have a hand of 2-3.5, whereas fabrics that have been treated with PVCL have a hand of 3-4. This is proof that PVCL has no negative effects on the hand. Hand is preferable to untreated materials for some treated fabrics. Some treated fabrics, on the other hand, aren't soft enough and are too slippery. Softener can be added to the solution in this scenario. Combinations of polymer and softener were developed and applied to the fabrics. As a result, the hand value of these textiles was 4-5, and the softener had no effect on the materials' pilling values. It can be said that using appropriate softeners as additives to improve the hand of the applied fabrics has no disadvantages.

3.8 The impact of polymer on fabric whiteness values

White fabrics (F1 and F2) were treated with 50 g/l PVCL and subjected to 130°C and 170°C for 1 minute in a Mathis-stenter frame to study the yellowing effect of PVCL. The Datacolor 600TM equipment was used to determine the whiteness value of these fabrics and results (in Berger unit) are shown in Table 6. The whiteness degree for untreated F-1 is a Berger value of 54.8. At 130°C fabric's whiteness value was likewise assessed and recorded as 55.6 Berger. However, it is clearly demonstrated that F-1 turn yellow at 170°C and the whiteness value is measured as 59.8 Berger, means F-1 is negatively affected at this temperature. The results are similar for F-2 fabric. When the findings were examined, it was evident that there was no significant change, indicating that PVCL has no influence on fabric whiteness at 130°C.

4. CONCLUSION

- PVCL was synthesized and characterized successfully. Fabrics (F1-F7) were treated with different concentrations of PVCL. Pilling values of treated fabrics were measured and it is proved that PVCL is beneficial in increasing the pilling values of fabrics with approximately 1.5 degrees of pilling.
- Pilling values of treated fabrics with 40 g/l PVCL were recorded as 4.5-5, means almost no pills on the fabric surface.
- The hydrophilicity values of treated fabrics and untreated fabrics were also compared. It was found that PVCL improves hydrophilicity of the fabrics.
- PVCL gives good handle to fabrics and do not cause yellowing on fabrics at 130°C.
- The PVCL functional polymer was named as "RUCO-PLAST EPG 19041" to market it as an anti-pilling chemical on Rudolf-Duraner's product list.

Table 5. Hydrophilicity values of fabrics treated with different concentrations of PVCL

Artical	Hydrophilicity values of untreated fabrics	Hydrophilicity values of treated fabrics with 20 g/l PVCL	Hydrophilicity values of treated fabric with 30 g/l PVCL	Hydrophilicity values of treated fabric with 40 g/l PVCL	Hydrophilicity values of treated fabric with 50 g/l PVCL
F-1	10 s	3 s	2 s	1 s	1 s
F-2	6 s	3 s	3 s	2 s	2 s
F-3	1 s	1 s	1 s	1 s	1 s
F-4	1 s	1 s	1 s	1 s	1 s
F-5	1 s	1 s	1 s	1 s	1 s
F-6	4 min	1.5 min	40 s	8 s	6 s
F-7	50 s	7 s	4 s.	1 s	1 s

Table 6. Comparing the degree of whiteness of the white fabrics treated with different temperatures and untreated ones

Artical	Whiteness degree of untreated fabric	Whiteness degree of treated fabric at 130°C	Whiteness degree of treated fabric at 170°C
F1	54.8	55.6	59.8
F2	52.7	53.2	60.4

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