Düzce University
Journal of Science & Technology

Research Article

Effects of Chemical and Surface Modification on Mechanical and Chemical Properties of Polyester Fabrics

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ABSTRACT

Alkali treatment of polyester fabrics is a common chemical modification process for forming a fabric with desirable qualities such as soft cloth, fabric regain, water absorbency, and fabric pilling with draping. However, if the optimization of the chemical treatment was not maintained, there could be serious decrease in mechanical strength of polyester fabrics. In this study, surface modification via low-temperature plasma application (<50 ^{0}C) was used as an alternative to chemical modification of polyester fabrics with alkaline treatment and the effects of both chemical and surface modification on mechanical and chemical properties of polyester fabrics were investigated. Parameters of chemical modification such as exposure time and concentration of alkali were varied while different exposure time was used in plasma application as a surface modification treatment. Performance tests such as mechanical strength, loss of weight and hydrophilicity of polyester fabrics were tested after each modification. Scanning electron microscope (SEM) micrographs were characterized as well. According to the test results; loss of weight of polyester fabrics after chemical modification was more than occurred right after surface modification. Advantages of surface modification on polyester fabrics were clearly seen in this study, especially when compared to high concentration alkali treatment. It was also considered that these functionalized polyester fabrics could be used as an alternative platform for 3DP (three-dimentional printing) applications before deposition of thepolymers.

Keywords: *Alkaline treatment, Surface modification, Polyester fabrics, Plasma application*

Kimyasal ve Yüzey Modifikasyon İşlemlerinin Polyester Kumaşların Mekanik ve Kimyasal Özelliklerine Etkileri

ÖZET

Polyester kumaşların alkali ortamda işlem görmesi kumaşların yumuşak tutum, hidrofilik karakter kazanması, dökümlü bir kumaş haline gelmesi gibi istenen özelliklere sahip olmasını sağlayan alışılmış bir uygulamadır. Fakat yapılan bu kimyasal modifikasyon işleminin parametreleri optimize edilmediğinde, polyester kumaşların

Received: 14/06/2017, Revised: 13/06/2018, Accepted: 19/06/2018

mekanik mukavemetlerinde ciddi düşüşler görülebilmektedir. Bu çalışmada, düşük sıcaklıkta yapılan (<50 0C) plazma aplikasyonu ile yüzey modifikasyon işlemi; polyester kumaşların kimyasal modifikasyon işlemlerine bir alternatif olarak kullanılmıştır ve her iki modifikasyon işleminin polyester kumaşların mekanik ve kimyasal özelliklerine olan etkileri incelenmiştir. Süre ve konsantrasyon gibi kimyasal modifikasyon işleminin parametreleri çeşitlendirilirken, yüzey modifikasyon işleminde kumaşlar farklı plazma işlem sürelerine tabi tutulmuştur. Her iki modifikasyondan sonra, polyester kumaşların mekanik özellikleri, hidrofilite değerleri ve ağırlık kayıpları gibi performans değerleri incelenmiş, taramalı elektron mikroskobu (SEM) görüntüleri alınmıştır. Test sonuçlarına göre; kimyasal modifikasyondan sonra kumaşlarda oluşan ağırlık kaybı plazma işlemi ile yapılan yüzey modifikasyonu işlemine oranla daha fazla olmuştur. Bu çalışmada, özellikle yüksek konsantrasyonda yapılan alkali işleme göre; polyester kumaşlara uygulanan yüzey modifikasyon işleminin pek çok avantajı görülmüştür. Fonksiyonelleştirilmiş bu polyester kumaşların üç boyutlu baskı uygulamalarında polimer aktarılmadan önce alternatif bir platform olarak kullanılabileceği düşünülmüştür.

Anahtar Kelimeler: *Alkali işlem, Yüzey modifikasyonu, Polyester kumaş, Plazma işlemi*

I. INTRODUCTION

Polyester fabrics are frequently used in the textile industry including outdoor, sports and active wear, as well as protective clothing, medical textiles, automotive parts and in technical applications because of their excellent properties such as high strength, attractive handle, dimensional stability and easy-care. However their hydrophobic character is a significant disadvantage that weakens the physiological properties of fabrics and causes difficulties in finishing such as pilling, static, and lack of dyeability. Alkaline hydrolysis is one of the basic alternatives modifying polyester which received considerable attention because it improves handle, wettability, resistance to abrasion damage, soil-release and drape properties of polyester fabrics in a simple way without need of capital investment [1-2].

The mechanism of alkaline hydrolysis has been shown in Fig.1 which is based on the nucleophilic attack of a base on the electron-deficient carbonyl carbon along the PET main chain, causing scissions at the ester linkages and producing carboxyl and hydroxyl polar groups [3,4].

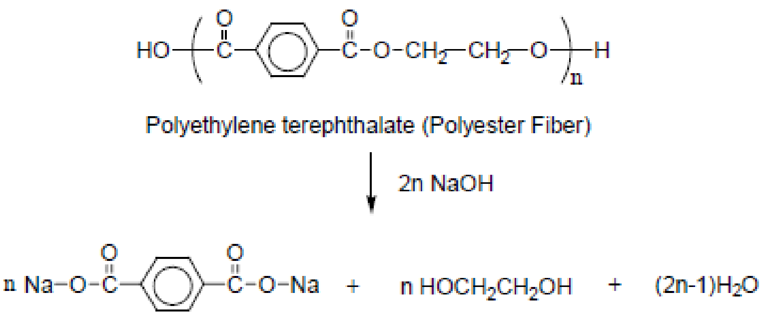


Figure 1. *The mechanism of alkaline hydrolysis of polyester fiber*

Alkaline hydrolysis, however, has a negative impact on the strength of polyester fabrics. Furthermore, it requires a high amount of sodium hydroxide and high operating temperatures [4]. In the literature

[5,6] it was indicated that after applying polyester fiber in strong alkaline bath for a certain period of time, peeling of outer layers of polyester fibers could be observed which leads to decreasing of fiber thickness.
Generally, textile processes consume high amounts of water, energy, and harsh chemicals. In order to reduce the environmental impact while obtaining improved fiber properties, environmental-friendly treatments such as plasma technology has been carried out [7,8]. Plasma is defined as fourth state of matter which is a partly ionized gas consisting of excited plasma species such as positive ions and free electrons, produced at room temperature, typically at low pressures [9].

Plasma surface modification has outstanding advantages compared to conventional textile finishing applications. Water and chemicals are not required resulting in reduction of pollutants which makes it cost-effective for effluent treatments. It is a dry, environmental-friendly and fast process which provides effective functionality on textile substrates with low consumption of dry-cure energy and chemicals. Besides, there are not remarkable changes in the bulk characteristics of materials treated through plasma process [10-12].

It was indicated in the literature that the enhancement on the wettability of polymeric materials could be improved by increase of the surface energy with plasma application. It was also determined that the main effects of the interaction between active chemical particles with a polymeric surface due to the plasma colliding was the breaking of molecule chains, the formation of new functional groups, like the formation of microporosity [9].

3DP (three-dimentional printing) technology has a big interest by the various industries such as automotive industry, aerospace, architecture, medical industries and tissue engineering because it provides producing and forming concept prototypes before production. The technology has got numerous advantages such as having low-cost, low-volume and low-risk way to market new innovative products such as scaffolds for tissue engineering or electronic sensors [13-15].The fused deposition modeling (FDM)which melts or softens the thermoplastic material is the commonly used technology in 3DP. The method uses temperature controlled extruder which pushes the thermoplastic filament through a heated extrusion nozzle and deposit molten polymer onto a platform. It can be an alternative way to improve functional textiles based on the deposition of functional polymers or compounds onto the surface of textile materials. [16]. Since polymer-textile adhesion property is a very important parameter to obtain effective 3D structures combined with textile materials [16], it is considered through this study that plasma application could be a better alternative than conventional methods before 3DP applications. A better adhesion can be obtained if the textile surface is roughened or hairy which could be obtained via surface modification by plasma treatment on textile substrates before deposition of polymers in 3DP applications. Adhesion of polyester textile substrate could be enhanced by low-frequency plasma application while increasing wettability of the surface of the polyester material in an environmental friendly way.

Thus in this study, low-temperature plasma surface modification (<50 ^{0}C) was carried out as an alternative to chemical modification of polyester fabrics with alkaline treatment and the effects of both chemical and surface modification on mechanical and chemical properties of polyester fabrics were investigated. Parameters of chemical modification such as exposure time and concentration of alkali were varied while different exposure time was used in oxygen plasma application as a surface modification treatment.

II. METHODS

In this study, 100 % woven polyester fabrics (200 g/m^2) were used as material. The treatment of polyester fabric in alkali medium was carried out using sodium hydroxide (purity > 97 %) with three different percentages as 8 %, 12 % and 16 % respectively. Exposure times for alkali treatment were varied as 20 min, 50 min and 80 min for each percentage of sodium hydroxide used in this study. In order to compare the mechanical and chemical characteristics of the fabrics after the treatment, surface modification by vacuum plasma device at low temperatures (< 50 ^{0}C) was performed as an alternative application for 1 min, 5 min and 10 min in low-frequency generator with oxygen gas carried out at a frequency of 40 kHz, at a pressure of 0.3 mbar and at 90W power. Experimental set-up and codes of samples (A means alkali treated sample, P means plasma treated samples) were shown in Table 1.

Table 1. *Experimental set-up*

Samples	Concentration of alkali (%)	Exposure time (min)
1A	8	80
2A	8	50
3A	8	20
4A	12	80
5A	12	50
6A	12	20
7A	16	80
8A	16	50
9A	16	20
1P	-	10
2P	-	5
3P	-	1

III. RESULTS AND DISCUSSION

A. MECHANICAL STRENGTH AND WEIGHT LOSS RESULTS

Tensile strengths of the samples were measured by an Instron Model Universal Testing Machine with a gauge length of 100 mm and a crosshead speed of 100 mm/min. Weight losses of both plasma treated and alkali treated polyester fabrics were measured. In Table 2, test results of mechanical strength and weight losses of samples were indicated. According to the test results, it was indicated that there was a significant decrease both in weight losses and tensile strengths of all alkali treated polyester fabrics when compared to oxygen plasma treated polyester fabrics. It was considered that this result was obtained because alkali hydrolysis caused scissions at the ester linkages which have a link to strength and weight losses while plasma treatment was effective only on the surface of the material without effecting bulk properties. The most decrease in tensile strength with the 40.2 % was observed in the sample 7A which had the highest concentration of sodium hydroxide for the maximum exposure time. On the other hand, when the plasma-treated polyester fabrics were examined, it could be clearly seen that the decreases both in weight losses and mechanical strength was much lower than the alkali treated samples.

Table 2.*Mechanical strength and weight loss resultsof untreated and treated polyester fabrics*

Samples	**Max. Load (kN)**	**(%)**	**Weight (g)**	**Weight Loss (%)**
Untreated	0.6750	-	37.72	-
1A	0.5672	16.4	35.78	5.14
2A	0.5879	13.4	35.87	4.90
3A	0.6026	10.5	36.34	3.65
4A	0.4712	29.8	34.53	8.45
5A	0.5246	22.3	34.93	7.39
6A	0.5526	17.9	35.10	6.94
7A	0.4020	40.2	33.16	12.08
8A	0.4423	34.3	33.98	11.27
9A	0.4866	28.3	34.38	8.85
1P	0.6145	8.9	36.48	3.28
2P	0.6334	5.8	36.65	2.83
3P	0.6446	4.5	36.89	2.21

B. WICKING HYDROPHILICITY TEST RESULTS

According to DIN 53924 standard, the wicking hydrophilicity test was carried out. During the test, the height of water reached after 300 sec of untreated, plasma-treated and alkali-treated samples were measured and reported. As it is seen in Fig. 2, the plasma treatment improved the wettability property of the fabrics significantly. On top of that, the hydrophilicity of the treated fabrics was increased when exposure time of the plasma application increased with the same operating parameters. The water absorption increased from 10.2 cm to 16.2 cm compared to the untreated sample after 10 min plasma treatment. When the samples treated in alkali medium was examined, it could be seen that sample 7A which had the highest concentration of alkali for 80 min had lower height of water after 300 sec when compared to 10 min oxygen plasma treated polyester fabrics. It was considered that both alkali treatment and plasma treatment had a positive effect on improving hydrophilic character of polyester fabrics; however plasma application was more effective than alkali treatment with the advantage of being a fast, dry and environmental-friendly process unlike the wet processes in textile finishing such as alkali treatments.

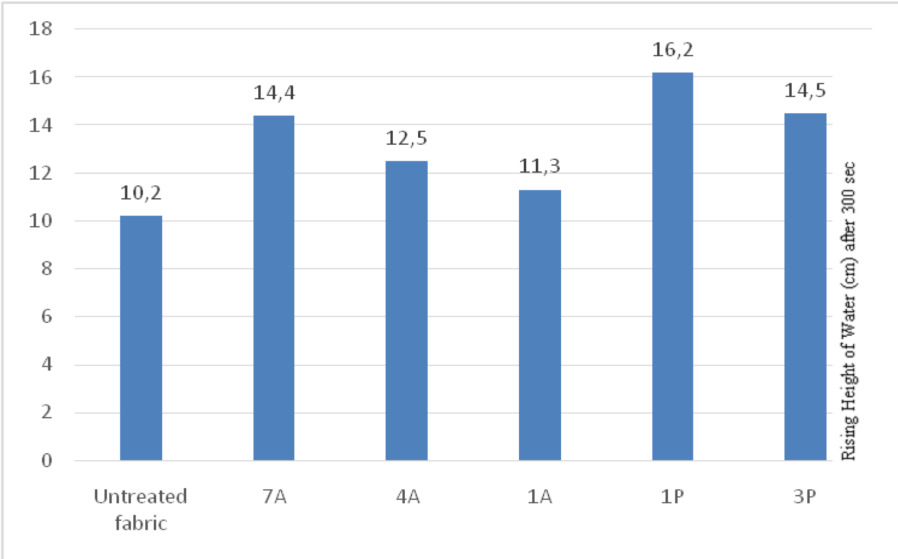
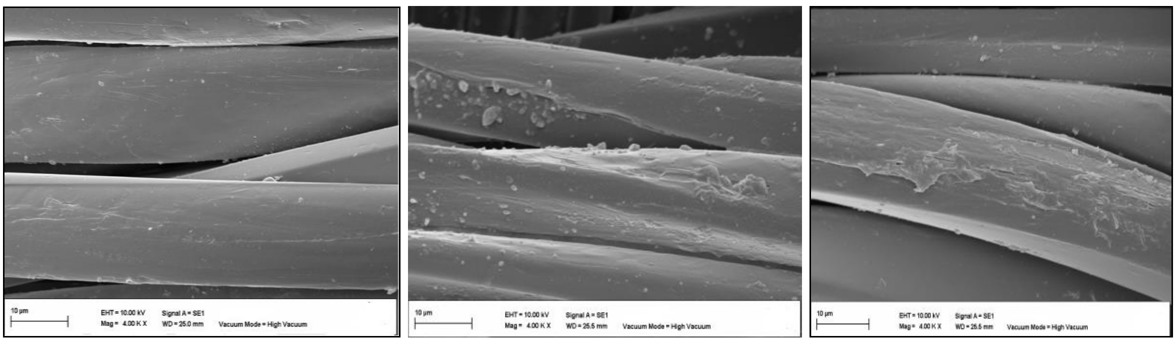


Figure 2. *Wicking hydrophilicity test results of untreated and treated polyester fabrics*

C. SCANNING ELECTRON MICROSCOPY ANALYSIS (SEM) RESULTS

For SEM test, selected textile materials were scanned by a Hitachi S-3200N electron microscope under a high vacuum at 4000 magnification. In Fig. 3, SEM photographs of the untreated, alkali-treated with 16 % NaOH for 80 min and plasma-treated for 10 min were shown, respectively. In Fig. 3a, it was determined that the surface of untreated fabric was very smooth. However, it could be seen that after the alkali treatment there were small particles and residues of sodium hydroxide on the polyester fibre surface in Fig. 3b while the surface roughness and grooving can be indicated on the surface of the polyester fabric which treated with plasma application in Fig. 3c. This result can be attributed to the etching effect caused by the bombardment of the plasma species on the polymer surface. Since there was a chemical modification on polyester fabric observed in Fig. 3b and surface modification of polyester fabric was indicated in Fig. 3c, functional groups were obtained on the surface which could be a proof for results of wicking hydrophilicity test.

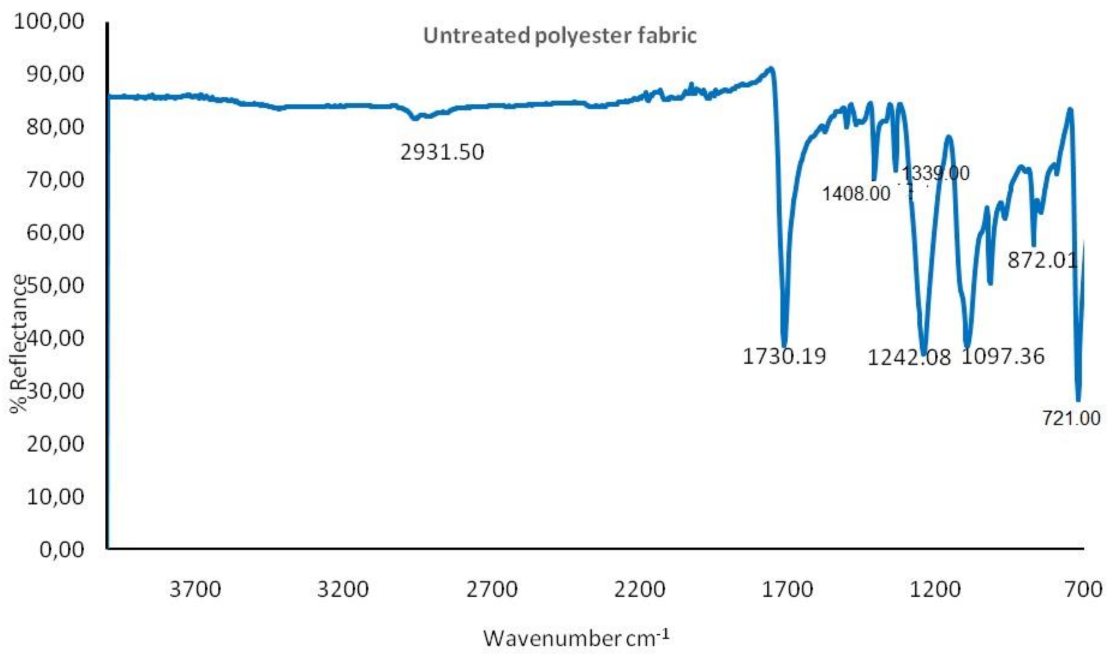


a) **b)** **c)**

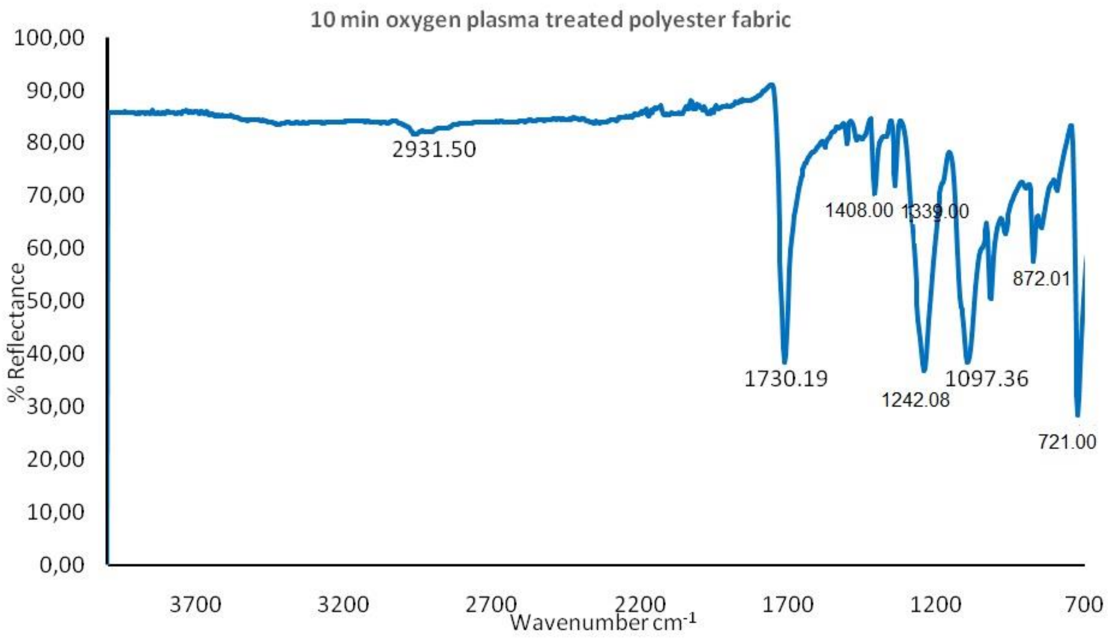
Figure 3. *SEM micrographs of* ***a)*** *Untreated* ***b)*** *7A (16 % NaOH treated for 80 min)* ***c)*** *1P (plasma treated for10 min)*

D. FOURIER TRANSFORM INFRARED (ATTENUATED TOTAL REFLECTANCE) SPECTRA ANALYSIS (FTIR-ATR) RESULTS

FTIR-ATR spectrums of samples were collected using a Nicolet 510P in the range of 525–4000 cm^{-1}. In Fig. 4a, the characteristic spectra of polyester fabric could be seen which had a stretching vibration band of C=O at 1730 cm^{-1}, C-O-C stretching vibration band at 1097 cm^{-1} and 1240 cm^{-1}. All these peaks confirmed the existence of ester linkage [6]. As it was shown in Fig. 4a and Fig. 4b, there was no significant change in spectrums which indicates the wave lengths of untreated and plasma treated polyester fabrics. It was considered that; since plasma treatment made only surface modification on the material via gas application without changing bulk properties of polyester fabric, significant change couldn't be observed when untreated and plasma treated fabrics were compared to each other. It was also indicated in the literature [9] that the infrared equipment by itself was not the most optimum one to identify the chemical changing on the plasma treated sample's surface unless wet chemical process was carried out after surface modification. Differently from Fig. 4a and Fig. 4b, there was an additional peak detected at 2359 cm^{-1} in Fig. 4c which was treated with sodium hydroxide. This was attributed to the carboxylic group (-COOH), introduced on the surface due to hydrolysis of the ester linkage [6].



a)



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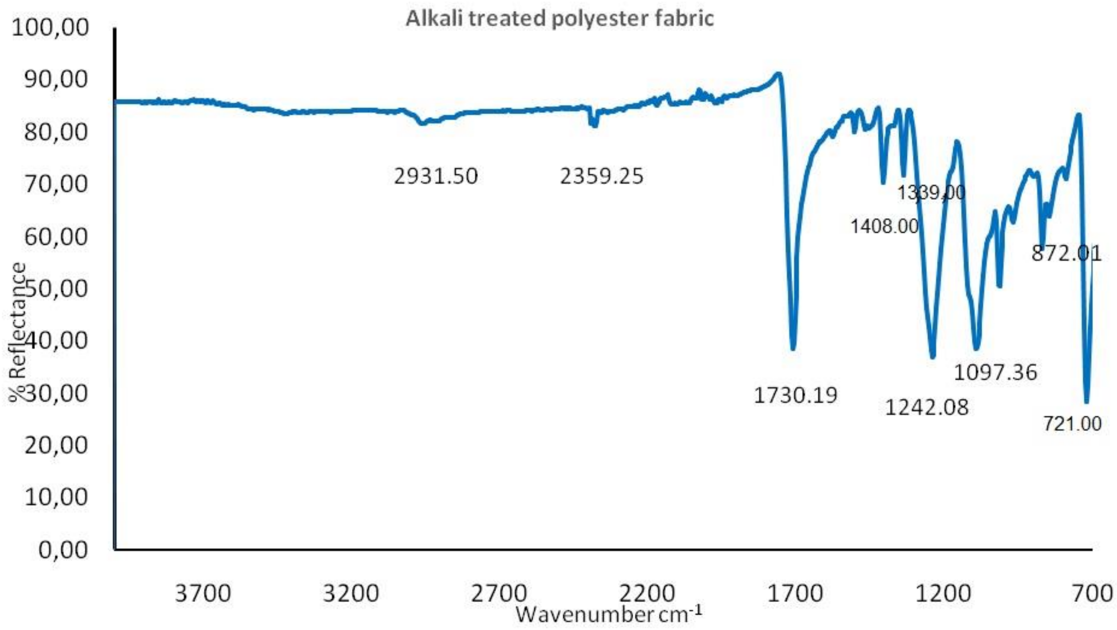

c)

Figure 4. *FTIR-ATR spectrum of* ***a)*** *Untreated* ***b)*** *1P (plasma treated for10 min)****c)*** *7A (16 % NaOH treated for 80 min)*

IV. CONCLUSION

In this study, surface modification by low temperature plasma application (<50 ^{0}C) were used as an alternative to chemical modification of polyester fabrics with alkaline treatment which could cause a serious decrease in mechanical strength of polyester fabrics due to hydrolysis of ester linkages. According to the test results, it was indicated that both alkali and plasma treatment improved the wettability character of polyester fabric, however plasma application was more effective than alkali treatment with the advantage of being a fast, dry and environmental-friendly process at room temperatures. Alkali treatment caused a significant decrease in mechanical strengths of the polyester fabric while this decrease was in very small range in plasma application. It was considered in this study that plasma treatment could be applied on polyester material in order to produce the desirable qualities such as soft cloth, fabric regain and improved hydrophilic character with an environmental-friendly manner compared to chemical modification with sodium hydroxide which generally consumes high amount of chemical at high temperatures. It was also considered that these functionalized polyester fabrics could be used as an alternative platform for 3DP applications before deposition of the polymers because of enhanced hydrophilic and adhesive effect of polyester fabric with surface roughness observed in SEM images.

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