Egypt. J. Chem. **Vol. 65,** No.8, pp. 779 - 789 (2022)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Evaluation and *CLO3D* Simulation of Some Characteristics of Bio-treated Knitted Polyester/Lycra Fabrics

R. F. El-Newashy[a] and H. El-Sayed[*b]

[a]*Clothing & Knitting Industries Research Department, Textile Research and Technology Institute, National Research Centre, Cairo, Egypt, Affiliation ID: 60014618.*

[b]*Proteinic and Man-made Fibres Department, Textile Research and Technology Institute, National Research Centre, Cairo, Egypt, Affiliation ID: 60014618.*

Abstract

The knitted fabrics which are used in the manufacture of sportswear should be fitting to some parts of the body with enough stretch-ability; namely the breast area including the under-arms. Herein, we adopt *CLO3D* simulation system to assign the proper blending ratio and fabric weight of selected bio-treated knitted polyester/Lycra (PET/L) blended fabric for manufacture of sportswear. Three different blending ratios (96/4, 94/6 and 92/8) with three different fabric weights; light (160 g/m^2), medium (200 g/m^2), and heavy (250 g/m^2) of PET/L knitted fabrics were fabricated. These fabrics were bio-treated with the lipolytic enzyme Lipolase 100L-EX to enhance the fabric hydrophilicity and to reduce the accumulation of electrostatic charge on the fabric surface without severe loss in fabric weight and burst force. Results of this investigation revealed that the light and medium weight bio-treated PET/L (92/8) knitted fabric exhibited the highest hydrophilicity and lowest electrostatic charge; thus they have been selected for evaluation by *CLO3D* simulation system. The selected bio-treated samples were found to have appropriate fitting (pressure) and stretch-ability at the shoulders, under-arms, and breast areas of a soft bra usually used in some women's sportswear. Bio-treatment of the said fabric with Lipolase 100L-EX had no significant effect on the fabric thickness and air permeability. The polyester component of the bio-treated PET/L knitted fabrics was found to be dyeable with the cationic dye C.I. Basic Red 18. The scanning electron microscopy revealed no deterioration in bio-treated knitted fabrics which assures that the used lipase enzyme is a benign reagent for activation of the polyester fibre surface.

Keywords: Polyester, Lycra, knitted fabric, enzyme, *CLO3D*, simulation

1. Introduction

Within the last two decades, cloth simulation systems have been commonly used in evaluation of textile products. The values of the various inherent properties of the fabric are the principal simulation parameters. These properties include physical and mechanical properties such as the fabric density, stretch stiffness, and bending stiffness [1].

Virtual try-on technology has been recently adopted for the 3D-visualization of garments and fabric drape on a3Davatar. The leading 3D fashion simulation systems have been V-Stitcher TM created by Browz-wear, the 3DVirtual Prototyping and 3D Suite by Optitex, and *CLO3D*. By applying this software, the fashion designers will be able to assign and generate garments with tailored properties and evaluate up to nine different garment-designs using a virtual model [2].

The 3D simulation software is classified into two classes regarding the creation of three-dimensional designs. The first class allows the designers to create garment silhouettes within the three-dimensional simulation software. The second class of software makes it possible to import *2D*flat patterns to wrap around and drape digitally on a virtual avatar. *CLO3D* is an innovative simulation software that merges between the advantages of the aforementioned two classes [3].

Polyester fabric produced from polyethylene terephthalate is the leading synthetic polymer used in textiles. In spite of the outstanding appearance, performance and comfort attributes exhibited by natural fibres, like cotton, wool, and silk [4–6], yet synthetic fibres constitute about two-thirds of all

*Corresponding author e-mail: hosam@trdegypt.org
Receive Date: 15 July 2022, Revise Date: 25 July 2022, Accept Date: 02 August 2022
DOI: 10.21608/EJCHEM.2022.150365.6512

textile market, from which polyester represents more than half [7]. Knitted polyester fabric has a large market share as they are used in the manufacture of textile items like shirts, sportswear, swimwear, leggings, socks, sweatshirts, and cardigans. The knitted products are stretchy, flexible, soft, and wrinkle-resistant. Knitwear has the disadvantage of being easy to damage and difficult to sew [8].

The performance and comfort attributes of polyester knitted as well as woven fabrics were improved by different methods [9–13]. Creation of new functional groups on the polyester fabric surface would improve its hydrophilic characters and reduce the accumulated electrostatic charge. Bio-treatment of polyester fabrics using ester-bond breaking enzymes were used by many authors to enhance the hydrophilic characters as well as dyeability and to reduce the accumulation of electrostatic charge on the fabric surface [14–17]. Different classes of enzymes have been utilized in bioprocessing of textile substrates to impart certain desired properties [18–20]. Lipase is an appropriate class of enzymes for hydrolysis of the ester bond along polyethylene terephthalate macromolecules. Lipases have been also utilized in removal of lipid barriers from wool fibres' surfaces, and to removing fatty matter from cotton fibres.

Stretch fiber or fabric affords the elasticity essential for the response of the garment to the body movement followed by return to its original size and shape [21]. Small ratio of Lycra in textile fabric provides superior stretch-ability to the final product, and many properties of the fabric will change accordingly. It has been reported that the percentage of Lycra extension is relatively high in any Lycra-containing fabric; and accordingly, the course density, wale density, and thickness of the said fabric are usually high, while the air permeability and initial are relatively low [22].Therefore, most of sportswear contains various ratios of Lycra to impart the appropriate stretching percentage.

In this investigation, knitted polyester/Lycra fabrics with different blending ratios and fabric weights were bio-treated with lipase enzyme to improve some of its surface characteristics such as water absorption ability and reduced electrostatic charge. Based on the properties of the bio-treated fabrics, two samples were selected for *CLO3D* simulation analysis to assign the proper blending ratio and fabric weight for the manufacture of some women's sportswear.

2. Experimental:

2.1. Materials

Polyester/Lycra blend yarns (30/1) with different blending ratio 96/4, 94/6, and 92/8 were used in this investigation.

The lipase enzyme (E.C. 3.1.1.3) Lipolase 100L-EX was purchased from ThermomycesLanoginosus solution, Sigma-Aldrich, USA. The declared enzyme lipolytic activity is 500 U/mg.

The cationic dye C.I. Basic Red 18 was purchased from Wenzhou Color Bloom New Materials Co. Ltd., Wenzhou, China.

2.2. Methods

2.2.1. Fabrication

Piquepolyester/Lycra knitted fabric was manufactured from polyester/Lycra yarns of different blend ratio (96/4, 94/6, and 92/8) at El-Chourbagui Textiles, Giza, Egypt. Three different fabric weights were prepared; namely high (250 g/m^2), medium (200 g/m^2), and low (160 g/m^2). The properties of the manufactured fabrics are summarized in Table 1.

Table 1: Polyester/Lycra knitted fabric characteristics.

Sample	Fabrics structure	Material	Ratio (%)	Weight (g/m^2)	Loop length (mm)	Count of rows (cm)	Count ofcolumns (cm)	Thickness (mm)
1	Pique knitted	Polyester/ Lycra	96/4	Low	3.6	68	31	0.92
2			96/4	Medium	2.8	55	31	0.89
3			96/4	High	3.4	79	31	0.85
4			94/6	Low	3.9	82	32	0.95
5			94/6	Medium	3.7	67	32	0.9
6			94/6	High	3.3	71	32	0.93
7			92/8	Low	3.6	68	30	0.97
8			92/8	Medium	3.3	74	30	0.96
9			92/8	High	3.8	82	30	0.93

2.2.2. Treatment

Polyester fabrics were bio-treated with an aqueous solution containing 2.0% (o.w.f.) of Lipolase 100L-EX for 60 min; the material-to-liquor ratio (MLR) was 1:50. The treatment temperature was maintained at 40° C and pH 8 which are the optimum conditions for maximum enzyme activity [23].

2.2.3. Dyeing

Bio-treated as well as untreated fabrics were dyed in an aqueous solution containing 1% (o.w.f.) C.I.

Basic Red 18 at 90 °C for 60 min. The pH of the dyebath was adjusted at 5.0 using acetic acid.

2.3. Analyses and testing

2.3.1. Physico-mechanical properties

The fabric thickness was measured in accordance with the ASTM D-1777-96 standard method using SMD-55.

The fabric weight of the treated as well as untreated wool samples was determined according to ASTM-D3776-96. The weight loss (%) of enzyme-treated wool was calculated according to the following (Equation 1):

$$Weight\ loss\ \% = \frac{W_1 - W_2}{W_1} \times 100 \quad (Eqn\ 1)$$

where W_1: is the dry weight of sample before treatment and W_2: is the dry weight of sample after treatment.

The fabric burst strength was tested by using Tinius Olsen material testing machine 500 according to ASTM D3787-2001 by applying 50 kgf load, 95 mm extension range, head speed of 305 mm/min, 90 mm endpoint and 0.1 kgf preload.

The fabric stiffness of untreated as well as treated samples was assessed in accordance with ASTM D-1388-2018.

Air permeability of the examined fabrics was measured on FX 3300 air permeability tester (TEXTEST AG, Switzerland) at a pressure of 100 Pa according to ASTM D737 standard method.

The water absorption test was assessed according to ASTM-D 1913 (American Test Method for Water Repellency; Water Spray Test new edition 2010).

The surface resistivity was measured for the pre-conditioned samples in a standard atmosphere according to the test method AATCC 76-2000. The resistance of the tested samples was measured on both sides; and the surface resistivity was calculated from the following (Equation 2):

$$\boldsymbol{\rho = \frac{RA}{L}} \quad (Eqn.2)$$

where; ρ is the surface resistivity in ohms/square, "R" is the bulk resistivity in ohms, "L" is the sample length in cm, and "A" is the sample cross-sectional area in cm^2[24].

2.3.2. CLO3D simulation system

Fabrics were tested according to *CLO3D* standard method to import the fabric properties to the software and simulate it [25]. As per the *CLO3D* simulation system, these fabric properties are stretchability, bending length, weight, and thickness. From these parameters, the system deduces the shear and density of the fabrics. The DC % was then calculated according to the following (Equation 3) [26]:

$$\mathrm{DC}(\%) = \left[\frac{A_s - A_d}{A_D - A_d}\right] \times 100 \quad (Eqn.3)$$

Where: "A_s" is the area of the shadow obtained from the projection of the draping fabric specimen by cm^2, "A_d" is the area of the shadow obtained from the projection of the sample holder in the initial position by cm^2, "A_D" is the area of the shadow obtained from the projection of the fabric specimen in the initial position by cm^2.

The pressure values were investigated using fabric pressure map mode on the software. The *CLO3D*-Avatar system was used for virtual garment fitting. The pattern pieces were drafted using tools available in the software. The system contributes to improve the quality of designs by checking silhouette and fit sooner in the development process [27].

2.3.3. Scanning Electron Microscopy

The alteration in the fabric surface morphology was monitored using Bruker Nano GmbH Scanning Electron Microscope D-12489 Berlin, Germany.

2.3.4. Colour measurements

The color strength (K/S) of dyed fabrics was measured using the light reflectance technique in accordance with the *Kubelka-Munk* equation (Equation 4) [28].

$$Color\ strength\ (K/S) = \frac{(1-R)^2}{2R} - \frac{(1-R^{\circ})^2}{2R^{\circ}} \quad (Eqn.4)$$

Where "R" and "R°"are the decimal fraction of the reflectance of the dyed and undyed fabrics, respectively. K is the absorption coefficient and S is the scattering coefficient.

3. Results and Discussion

3.1. Physico-mechanical properties of the bio-treated fabrics

The effects of bio-treatment of knitted polyethylene terephthalate/Lycra (PET/L) fabrics of different blending ratios and fabric weights with the lipolytic enzyme Lipolase 100L-EX, on some of its physico-mechanical properties were assessed and the results were presented in Figures 1 (a-e).

Figure 1-a indicates that bio-treatment of PET/Lycra fabrics has no adverse effect on the fabric weight and the applied lipase enzyme, under the used experimental conditions, hydrolyzed limited number of ester bonds along the macromolecular structure of PET. Whereas the lowest weight loss was recorded in case of samples 7 and 8 (1.7 and 1.6, respectively), the maximum loss in weight (4.2 %) was observed in case of sample 4. These values are within the acceptable limits of the percent weight loss during wet processing of textiles.

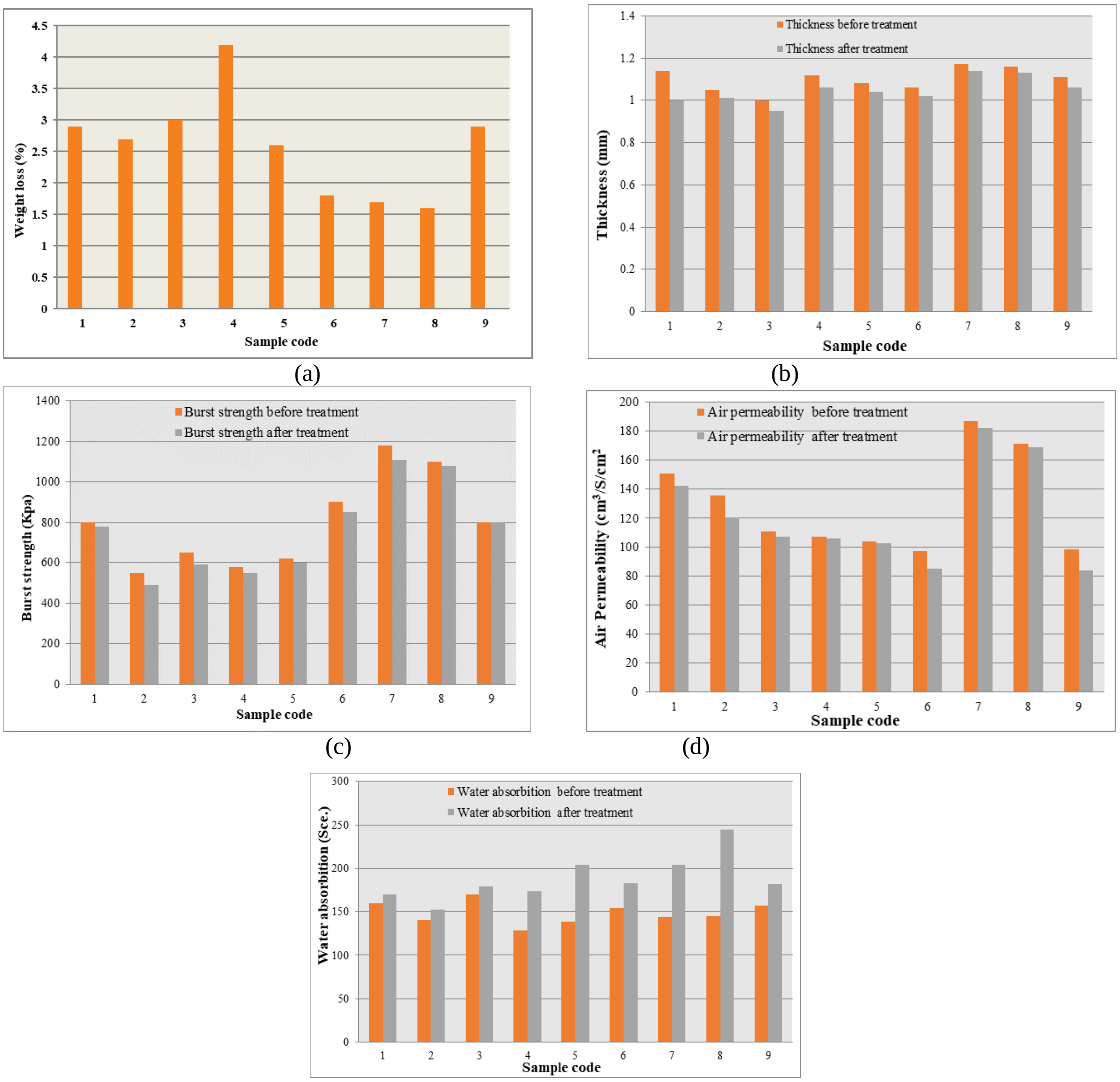
It is obvious from Figure 1-b that bio-treatment of PET/Lycra fabrics resulted in insignificant loss in the fabric thickness. These results are in harmony with the percent loss in weight of the bio-treated samples shown in Figure 1 and those of the burst strength shown in Figure 1-c.

Unlike alkali treatment of polyester fabrics, which is usually used to activate the fabric, bio-treatment of polyester-containing fabrics did not lead to severe loss in the fabric weight and strength [29]. This is considered as one of the advantages of enzymatic activation of PET fabric over alkali treatment.

The air permeability of the untreated PET/Lycra fabric varies according to the blending ratio and the fabric weight. As the Lycra content and the fabric weight increased, the porosity of the fabric decreased, and hence the air permeability decreased (Figure 1-d). Bio-treatment of wool with the said enzyme did not affect the fabric porosity, and hence the air permeability was not affected remarkably.

A On the other hand, the water absorption of bio-treated fabrics was enhanced remarkably to different extents depending on the fabric nature (Figure 1-e). This can be explained in terms of creation of hydrophilic carboxylic and hydroxyl groups along PET macromolecules under the influence of the lipase enzyme, as shown in Equation 5[30]. The highest improvement was found in sample 5 (medium weight 94/6 PET/L), 7 (light weight 92/8 PET/L) and 8 (medium weight 92/8 PET/L).

ffiliation(s) should be shown below the author name(s) and typed in Times New Roman 10-point, italic and non-boldface. At least one e-mail address is needed for corresponding with the author.



(a) (b) (c) (d) (e)

Figure1 (a-e): Effect of bio-treatment of with PET/L fabrics of different blending ratios on their wight (a), thickness (b), burst (c), air permeability (d), and water absorption (e)

$$-\overset{O}{\overset{\|}{C}}-O-PET + HOH \xrightarrow[\text{enzyme}]{\text{Lipase}} PET-\overset{O}{\overset{\|}{C}}-OH + PET\text{-}OH \qquad (Eqn.5)$$

Polyester Caroxylic end group Hydroxyl end group

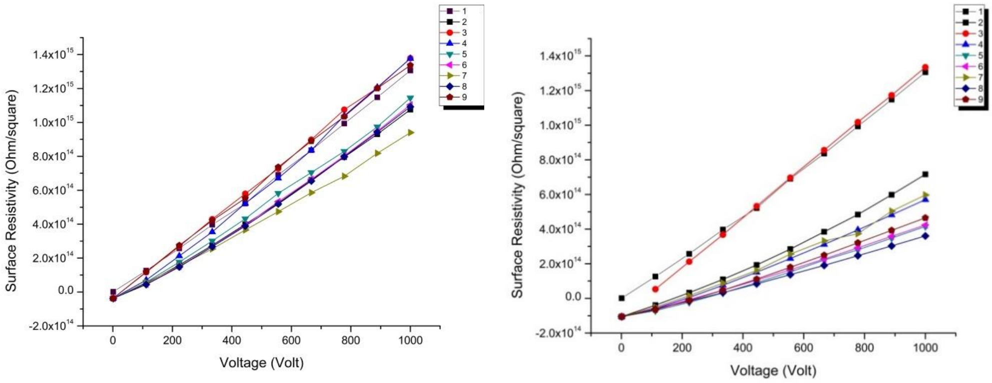


Fig. 2: Surface resistivity of untreated (left) and bio-treated (right) knitted PET/L blended fabrics with different blending ratios

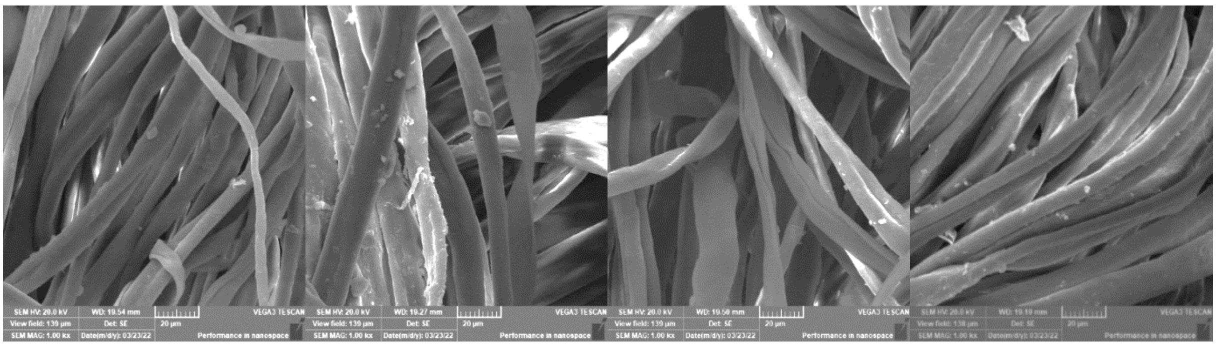
These findings match well with the surface resistivity measurements (Figure 2). The static charge on the fabric surfaces (indicated by the values of their surface resistivity) of the bio-treated samples 7 and 8 are lower than that on the corresponding untreated ones.

3.2. Fibre morphology

Scanning electron microscopy was adopted to monitor any change in the fibres topography of the bio-treated PET/L knitted fabric. Figure 3 (a–d) shows the scanning electron micrographs of untreated as well as bio-treated PET/L samples number 7 and 8. The micrographs 7a and 7b belong to the untreated PET/L samples 7 and 8, respectively in which the Lycra threads can be distinguished from the PET ones as the former are thinner and lighter, while the latter areof alteration in the fibre morphology without sever deterioration under the influence of the applied lipolytic enzyme.

3.3. Dyeability

The colour strength (K/S) of the dyed untreated as well as treated PET/L knitted fabrics towards C.I. Basic Red 18 was studied to find out whether the adopted bio-treatment method creates carboxylic groups within the PET part of the fabric. The results of this investigation, as shown in Table 2, imply that C.I. Basic Red 18 has nearly no substantivity towards PET/L fabrics as indicated by the relatively very low colour intensity values. On the other hand, the sharp increase in the colour intensities of the corresponding bio-treated and dyed samples could be attributed to the creation of carboxylic groups within the chemical structure of PET component in the bio-treated fabrics makes them dyeable with the used cationic dye.



(a) (b) (c) (d)

Figure 3: Scanning electron micrographs of untreated and bio-treated PET/L knitted fabric. **(a)** untreated sample number 7, **(c)** untreated sample number 8, **(b)** bio-treated sample number 7, and **(d)** bio-treated sample number 8

Table 2: The colour strength (at λ_{max} 490 nm) of the dyed untreated and bio-treated PET/L knitted fabrics

Sample code	Colour intensity (K/S)	
	Untreated	Bio-treated
1	0.14	1.91
2	0.11	2.84
3	0.11	2.32
4	0.14	2.96
5	0.12	3.42
6	0.15	2.91
7	0.13	3.69
8	0.12	3.75
9	0.13	2.87

3.4. Simulation model

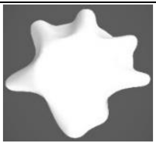
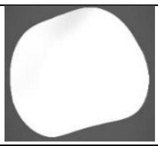
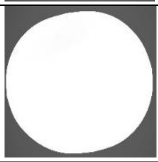
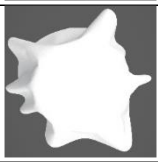
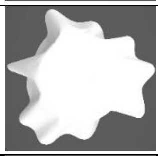
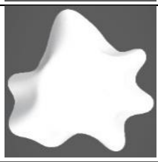
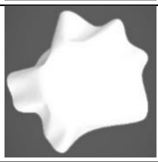
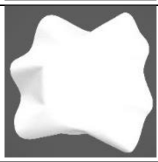
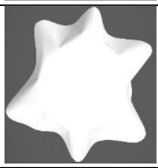
We used the *CLO3D* simulator, for an implementation soft bra on Avatars to assign the sample of higher stretch-ability and pressure which are essential requirements for specific sportswear [25]. The design elements and principles were determined in the studied sample to achieve the required fitting, and hence performance of the final product. The different parts of the implemented design were made to avoid the air gap, and the direction of parts within the pattern achieved the desired pressure on the breast area. The shoulder and underarm were fitting and adjacent to the body to attain the proper wearing comfort and functional performance. All the stitches were flat to protect PET/L knitted fabric from filament distortion, the stitch lines were curved to suit the breast area and form the human body and apply pressure harmonically.

Four parameters were entered to the *COL3D* system; namely bending stiffness, stretch-ability, weight, and thickness of the fabrics in both warp and weft directions. Two parameters were simulated from the system; namely shear and density; while the DC % was calculated. Table 3 summarizes the findings of these analyses; and the data therein elucidate that the samples number 7 & 8 have the optimum DC % which is appropriate for manufacturing of sportswear (soft bra) with the necessary fitting and stretchability. Based on the physico-mechanical properties as well as the DC % of the untreated and bio-treated samples, we chose samples numbers "7 & 8" for the *CLO3D* simulation.

The results of the *CLO3D* simulation regarding the stretchability and fitting of sportswear (soft bra) of untreated as well as bio-treated samples numbers 7 (92/8 light weight PET/L) and 8 (92/8 medium weight PET/L), respectively are shown in Figures 4and 5. The areas of red colour have the highest tension, while those of blue colour have the lowest tension. Thorough inspection of these figures elucidates the followings:

- The areas at the shoulder, breast and under-arm exhibit red colour in all bio-treated and untreated samples. These parts of sportswear are usually subjected to tension during movement and should be fitted well to the body.
- There are slight differences between the tensions at all areas between the untreated and corresponding bio-treated sample. This assures that the bio-treatment of PET/L has improved its hydrophilic characters without negative impact on its stretch-ability; presumably due to the fact that lipase enzyme will not affect Lycra which is the component responsible for the stretch-ability of the fabrics.
- The light and medium weight samples (for the same blending ratio) have similar patterns regarding the areas of high and low tensions.

Table 3: Fabric properties related to *CLO3D* simulation system

Fabric code	Visual drape	DC%	No. of Nodes	Stretch weft (%)	Stretch wrap (%)	shear	Bending length (cm)			Density (g/m^3)	Weight (g/m^2)	Thickness (mm)
							weft	warp	45			
1		38.25763	7	9	18	19	34	30	45	15	183.33	0.5
2		81.9553	4	22	28	9	91	91	91	16	187.88	0.5
3		91.64776		16	13	13	0	0	0	17	198.48	0.5
4		30.75018	8	63	63	63	52	36	24	19	216.67	0.5
5		36.76042	9	65	65	75	56	39	27	20	217.99	0.5
6		43.60321	7	35	10	12	51	47	35	16	187.88	0.5
7		48.92849	8	63	63	63	26	60	26	17	202.02	0.5
8		51.55046	7	63	63	63	25	65	23	18	211.62	0.5
9		41.48511	7	63	63	63	31	52	29	18	206.57	0.5

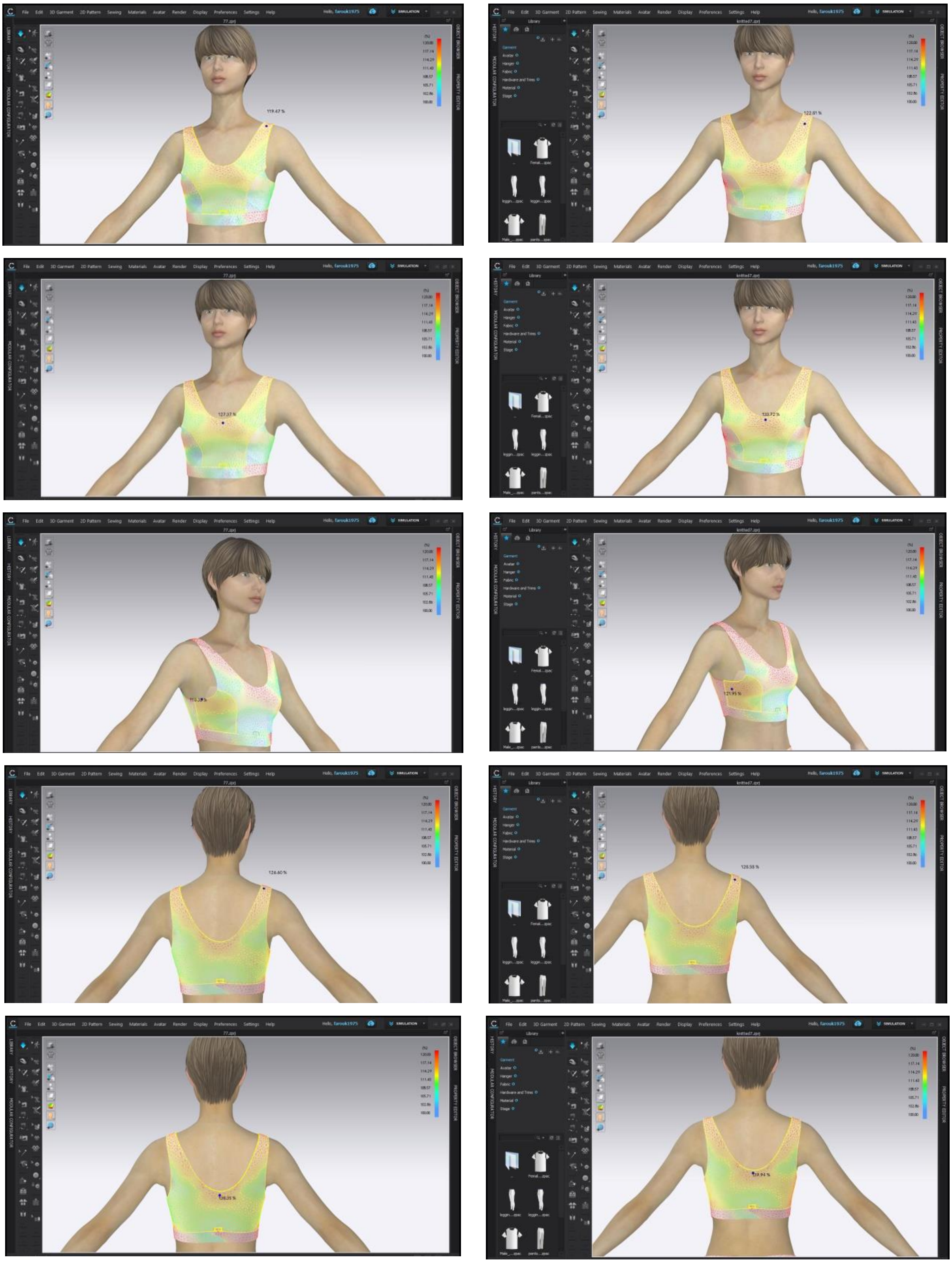


Figure 4: *CLO3D* Simulation System for evaluation of fitting and stretch-ability of sample number 7 (light weight 92/8 knitted PET/L blended fabric)

Figure 5: *CLO3D* Simulation System for evaluation of fitting and stretch-ability of sample number 8 (medium weight 92/8 knitted PET/L blended fabric)

4. CONCLUSION

The lipolytic enzyme Lipolase 110L-EX (2%, o.w.f.) was successfully utilized in bio-treatment of PET/L blended knitted fabrics to enhance their hydrophilicity and to reduce the accumulated electrostatic charge. The dyeability of the lipase-treated fabrics towards cationic dye was highly improved. Scanning electron micrographs of the bio-treated sample ensures that there was no fibre deterioration after being bio-treated with the said enzyme. The fibre weight, strength, and air permeability were not drastically affected.

Based on the findings of the of the physico-mechanical properties of the bio-treated fabrics, it is concluded that that lipase-treated light and medium weight PET/L (92/8) blended knitted fabrics are appropriate for manufacture of women's sportswear, especially those who have big breast. *CLO3D*-Avatar simulation system, the fitting (pressure) and stretch-ability of these fabrics at the shoulders, under-arms and breast are ideal for responding to the movement and fatigue exerted during movement and bending of the body upper parts and limbs of athletic women.

5. REFERENCES

[1] E. Ju,and M. G. Choi, Estimating cloth simulation parameters from a static drape using neural networks. *IEEE Access*, 8 (2020)195113-195121. https://doi.org/10.1109/ACCESS.2020.3033765.

[2] D. E. Kim, and K. LaBat, An exploratory study of users' evaluations of the accuracy and fidelity of a three-dimensional garment simulation. *Text. Res. J.*, 83(2)(2013)171-184. https://doi.org/10.1177/0040517512458339.

[3] A. S. M. Sayem, R. Kennon, and N. Clarke, 3D CAD systems for the clothing industry. *Int. J. Fash. Des. Technol. Educ.*, 3(2) (2010)45-53. https://doi:10.1080/17543261003689888.

[4] I. Hossain, M. Moniruzzaman, M. Maniruzzaman, and M. A. Jalil, Investigation of the effect of different process variables on color and physical properties of viscose and cotton knitted fabrics. *Heliyon*, 7(8) (2021), e07735. https://doi.org/10.1016/j.heliyon.2021.e07735.

[5] H. Ghazala, H. M. Helmy, H. M. Mashaly, and Tawfik A. Khattab. Development of Multifunctional Cotton/nylon Blended Fabrics Using Nanoparticles of Different Metal Oxides. *Egypt. J. Chem.*, 64(8) (2021)4387-4396. https://doi.org/10.21608/EJCHEM.2021.70442.3551.

[6] A. Kantouch, E. M. Khalil, S. Mowafi, O. G. Allam, and H. El-Sayed, Utilization of ionic liquids for low temperature dyeing of proteinic fabrics. *Egypt. J. Chem.*, 54(2) (2011)189-203.

[7] C. Palacios-Mateo, Y. van der Meer, and G. Seide, Analysis of the polyester clothing value chain to identify key intervention points for sustainability. *Environ. Sci. Eur.*, 33(1)(2021)1-25. https://doi.org/10.1186/s12302-020-00447-x

[8] P. Komárková, T. Mansoor, A. Ali, H.F. Siddique, A. Havelka, and Z. Hussain, Wrinkle free plaited knitted fabrics without pre-heat setting. *J. Text. Inst.*, 109(3)(2018)307-311. https://doi:10.1080/00405000.2017.1342585.

[9] H. Fahmy, H. Okda, M. Elrafie, A. Hassabo, and M. A. Youssef, Synthesis and Application of New Silicone Based Water Repellents. *Egypt. J. Chem.*, 65(2) (2022)499-507.https://doi.org/10.21608/EJCHEM.2021.89016.4275.

[10] R.F. El-Newashy, S. Mowafi, K. Haggag, M. AbouTaleb, and H. El-Sayed, Evaluation of comfort attributes of polyester knitted fabrics treated with sericin. *Fibers Polym.*,20(9) (2019)1992-2001. https://doi.org/10.1007/s12221-019-9275-3.

[11] R.F. El-Newashy, S. Mowafi, M. AbouTaleb, and H. El-Sayed, Enhancing electrical conductivity attributes of knitted polyester fabrics using znonano-particles. *Egypt. J. Chem.*, 63(9)(2020) 3191-3198. https://doi.org/10.21608/ejchem.2020.24432.2460.

[12] M. Abou Taleb, S. Mowafi, H. El-Sayed, R.F. El-Newashy, Facile development of electrically conductive comfortable fabrics using metal ions. *J. Ind. Text.*, 51(7) (2022) 1100-1120. https://doi.org/10.1177/1528083719893713.

[13] N.S. Elshemy, M.H. Elshakankery, S.M. Shahien, K. Haggag, and H. El-Sayed, Kinetic investigations on dyeing of different polyester fabrics using microwave irradiation. *Egypt. J. Chem.*, 60(2017), 79-88. https://doi.org/10.21608/ejchem.2017.1604.1131.

[14] H. M. E. El-Hennawi. New approach of biotechnology in textile coloration. *Egypt. J. Chem.*, 64(2) (2021)1075-1091. https://doi.org/10.21608/EJCHEM.2020.34098.2714.

[15] S. D. Wavhal, and R. H. Balasubramanya, Role of biotechnology in the treatment of polyester fabric. *Indian J. Microbiol.*, 51(2)(2011) 117-123. https://doi:10.1007/s12088-011-0163-9.

[16] A. Gao, H. Shen, H. Zhang, G. Feng, and K. Xie, Hydrophilic modification of polyester fabric by synergetic effect of biological enzymolysis and non-ionic surfactant, and applications in cleaner production. *J. Clean. Prod.*, 164(2017) 277-287. https://doi.org/10.1016/j.jclepro.2017.06.214.

[17] F. Kawai, T. Kawase, T. Shiono, H. Urakawa, S. Sukigara, C. Tu, and M. Yamamoto, Enzymatic hydrophilization of polyester fabrics using a recombinant cutinase Cut 190 and their surface

characterization. *J. Fiber Sci. Technol.*, 73(1) (2017) 8-18. https://doi.org/10.2115/fiberst.fiberst.2017-0002

[18] M. AbouTaleb, S.K. Gomaa, M. Wahba, R.A. Zaki, A.F. El-Fiky, H.A. El-Refai, and H. El-Sayed, Bioscouring of wool fibres using immobilized thermophilic lipase. *International Int. J. Biol. Macromol.*, 194(2022)800-810. https://doi.org/10.1016/j.ijbiomac.2021.11.128.

[19] A. F.El-Fiky, E. M.Khalil, S.Mowafi,R. A.Zaki, and H. El-Sayed, A novel approach towards removal of lipid barrier from wool fibers' surface using thermophilic lipase. *J. Nat. Fibers*, (2021) Published online. https://doi.org/10.1080/15440478.2021.1982835.

[20] H. El-Sayed, S. Mowafi, A.F. El-Fiky, and K.M. Khalil, Low temperature water-saving degumming of natural silk using thermophilic protease. *Sustain. Chem. Pharm.* 27(2022)100681 .https://doi.org/10.1016/j.scp.2022.100681

[21] N. Akter, M.R. Repon, D. Mikučionienė, M.A. Jalil, T. Islam, and M.R. Karim, Fabrication and characterization of stretchable denim fabric using core spun yarn. *Heliyon*, 7(12) (2021), e08532. https://doi.org/10.1016/j.heliyon.2021.e08532.

[22] R. Sadek, A.M. El-Hossini, A.S. Eldeeb, and A.A. Yassen, Effect of lycra extension percent on single jersey knitted fabric properties. *J. Eng. Fibers Fabr.*, 7(2) (2012),11-16. https://doi.org/10.1177/155892501200700203.

[23] W. El- Sayed, R. Nofal, and H. El- Sayed, Use of lipoprotein lipase in the improvement of some properties of wool fabrics. *Color. Technol.*, 126(5)(2010), 296-302. https://doi.org/10.1111/j.1478-4408.2010.00260.x.

[24] E. Kasaw, A. Haile, and M. Getnet, Conductive coatings of cotton fabric consisting of carbonized charcoal for E-Textile. *Coatings*, 10(6)(2020)579. https://doi.org/doi:10.3390/coatings10060579.

[25] CLO Virtual Fashion (2020). CLO [Online]. Available: https://www.clo3d.com. https://youtu.be/HA7HoK6_4Fk.

[26] A. Giwa, E.O. Achukwu, and M. Shebe, Measurement of fabric drape using digital image processing. *Afr. J. Plant. Sci.*, 13(2010)47-57.

[27] Ju, K., and Y. Jeong, Usage & education of the CLO 3D virtual clothing program in the development office & academic. *Fashion Information and Technology*, 13(2016)51-59.

[28] H. El-sayed, and N. El-Shemy, Utilization of red apple peel extract in dyeing of wool fabric. *J. Nat. Fibers*, (2021), Published online. https://doi.org/10.1080/15440478.2021.1993499.

[29] R. Rathinamoorthy, Axillary odour studies on alkali-treated knitted polyester fabric. *Int. J. Cloth. Sci. Technol.*, 29(2017)251-261. https://doi.org/10.1108/IJCST-05-2016-0057.

[30] I. Čorak, A. Tarbuk, D. Dorđević, K. Višić, and L. Botteri, Sustainable alkaline hydrolysis of polyester fabric at low temperature. *Materials*, 15(4) (2022) 1530. https://doi.org/10.3390/ma15041530.