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Research article

Comparative Analysis of the Effect of Heatsetting and Wet Processes on the Tensile Properties of Poly Lactic Acid (PLA) and Poly Ethylene Terephthalate (PET) knitted fabrics

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Abstract

Poly (lactic acid) (PLA) is biodegradable, melt processable and environmentally benign aliphatic polyester produced from the fermentation of natural renewable resources like corn, sugar and vegetable. The comparative analysis of the effect of time of heatsetting and wet processing from this research showed that PLA exhibited good textile properties for versatile end applications. This research comparatively studied the effect of time of heatsetting and wet processes on the tensile properties of Ingeo^{TM} Poly (lactic acid) (PLA) and Poly (ethylene terepthalate) (PET) fabrics using the Kawabata Evaluation System (KES-FB) for fabrics. The tensile properties of PLA and PET fabrics determined using the KES-FB were fabric Extension, EM [%], Linearity of Load Extension, LT [-], Tensile Energy [WT] g.cm/cm^2 and Tensile Resilience, RT [%]. Tensile properties were determined in both warp and weft directions to appreciate fabric anisotropy. Inorder to make for a comprehensive comparative analysis of the effect of heatsetting and wet processing on the tensile properties of knitted PLA and PET Fabrics, a total of sixteen fabrics were subjected to varying heatsetting temperatures of 15s, 30s, 45s, 60s, 90s, 120s and 240s, with subsequent wet processing phases including scouring, dyeing, alkaline clearing and softening followed by subjection to the KES-FB fabric evaluation system to cover fabric anisotropy. Results were used in understanding comparatively the tensile properties of Poly (lactic acid) (PLA) and Poly (ethylene terepthalate) (PET) knitted fabrics. **Copyright © IJMMT, all rights reserved.**

Keywords: Ingeo™ Poly (lactic acid) (PLA), Poly (ethylene terepthalate) (PET), KES-FB system, tensile extension EM [%], linearity of load extension [LT], tensile energy [WT] and tensile resilience [RT].

1.0 Introduction

Polylactic acid is aliphatic polyester obtained from renewable materials and considered ecofriendly. PLA is biodegradable and capable of degrading to carbon dioxide and water without causing harm to the environment. PLA can be produced from the polymerization of Lactic acid obtained from the fermentation of corn, sugar and vegetable and does not require any fossil fuels [1]. The production of PLA is attained through two major methods of ring polymerization of lactide and direct condensation polymerization of lactic acid. PLA fiber can be manufactured by both melt and solution spinning processes [18]. A thermal stabilizer is used in preventing thermal degradation of PLA during melt spinning. Ingeo Polylactic acid is the only synthetic fiber available in large commercial quantities and wholly produced from an annually renewable raw material source that is not oil [2]. The fundamental raw material for the production of Ingeo PLA is corn. Production of PLA is achieved by two major routes through direct condensation polymerization reaction of lactic acid and ring opening polymerization of lactide, a cyclic dimer of lactic acid, yielding poly(lactic acid, poly(d-lactic acid) or poly(d,l- lactic) acid depending on lactic acid isomers used [3]. Although Polylactic acid can be produced by both melt spinning and solution spinning, the former is used more regularly due to more eco friendliness and ease of processing [4]. The chemical structure of PLA is as shown in figure 1 below [4].

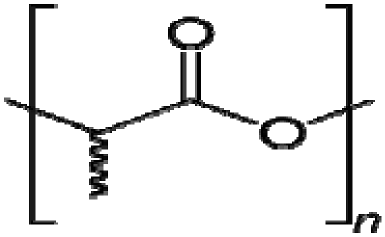

Figure 1: Chemical structure of Poly (lactic acid) (PLA)

PET is aromatic polyester, including a benzene ring in each repeat unit. PET fibers can be produced from terepthalic acid obtained by processing of benzene and ethylene glycol obtained from ethylene. The polymerization reaction occurs in a vacuum at high temperatures releasing water as a byproduct. This is followed by the melt extrusion process into staple, filament or tow form [2]. Polyester fibers are used in woven and knitted fabrics for apparel and household fabrics and in the construction of functional articles such as car seat belts, nets, ropes and fiber-fill. They are also applied in medical textiles. PET exhibits very good mechanical properties. The melting temperature of PET lies between 254°C and 260°C [5]. PET exhibits a high light resistance, UV and high abrasion resistance [6]. When properly treated PET fabric exhibits good dimensional stability, crease resistance and solvent resistance. PET when compared with other synthetic fabrics exhibits hydrophobicity and relative stability to chemicals and processing conditions [7]. At 65% r.h and 25°C, PET exhibits a good moisture regain of between 0.2 – 0.4% [8]. Textile fibers which are obtained from aliphatic polyester, poly (lactic acid) derived from an annually renewable resource such as corn is similar to the more reactive Polyethylene terepthalate (PET) due to the fact that they are dyeable using disperse dyes. Polylactic acid is hydrolytic sensitive and has a lower T_m (170°C) and hence cannot be dyed at high temperatures of 125°C – 130°C normally used for aqueous phase dyeing of PET having T_m of 250°C. Therefore, lower dyeing conditions of 110 – 115°C for 15 – 30 min at pH 4.4 – 5 are recommended for Polylactic acid [9].Disperse dyes generally behave differently on PLA fiber than on PET fiber displaying lower exhaustion [10, 17], with dyeing being brighter [11], of higher color yield and with maximum wavelength occurring at a shorter wavelength than on PET [12].

Scouring is an important process in the industrial wet processing of knitted PLA and PET fabrics. The essence of scouring is to remove impurities and surface contaminants. The scouring process is thought to have an impact on the fiber structure, properties and subsequently on the overall performance of dyeing [18]. Reduction clearing is a wet process of using caustic soda and sodium hydrosulphite ($Na_2S_2O_4$) to effectively remove dye which is unfixed at the surface of both PET and PLA fibers at 70°C within time duration of between 10 to 15 minutes. This is because PET and PLA fabrics may be contaminated with surface deposits of unfixed dyes after the dyeing process, especially at heavy depths of shade since there is tendencies for water insoluble disperse dyestuff to aggregate into relatively large particles as the dye bath cools down to below 100°C. Softening is a process which enhances the softening or handle of the fabric through the use of appropriate chemicals called softeners. The application of softeners introduces a level of softness which may not be attained by mechanical finishing or modification of fabric construction. Synthetic fibers are manufactured by extrusion through spinnerets to form filaments which in turn impacts stress which are generated within the polymer structure and once the filament cools down, this stress is trapped in the material structure. Dimensional stability is in turn impacted into the fiber when exposed to wet or heat treatments. Stress relaxation is thus impacted into the fiber and results in shrinkage of the fibers. Heatsetting the fiber thus introduces enhanced dimensional stability to the fibers improving fiber morphology and orientation. The heatsetting process is determined by the temperature, time of heatsetting, the medium of heatsetting (air, solvents or water) and the tension applied to the substrates during heatsetting. The heatsetting temperature should be higher than the maximum temperature of the subsequent wet processes such as dyeing and ironing temperature so as to ensure the fabric attains dimensional stability [13]. For PET, heatsetting occurs at temperatures of $130^{o}C$-$140^{O}C$ in steam or $190^{o}C$ $220^{O}C$ in dry air in the presence of some tension and since T_g of PET is approximately $80^{o}C$, heatsetting of PET above its Tg would allow the polymer structure attain dimensional stability [14].

The Kawabata Evaluation System is an industrial standard of determination of fabric handle through an objective mode of assessment [15]. KES measures a series of fabric properties at low stresses comparable to those the fabric undergoes during normal handling, tailoring, wearing and other end user applications [16]. In this research, the Kawabata was used in determining specifically the following tensile properties of both PLA and PET (table 1):

Table 1: Tensile properties determined using the KES-FB

PROPERTY	DEFINITION
TENSILE	
Extensibility (EM)	% Extension at maximum applied load of 500g/cm
Tensile energy (WT)	Energy in extending fabric to 500g/cm
Linearity of load-extension curve (LT)	Linearity of load-extension curve
Tensile resilience (RT)	% Energy recovery from tensile deformation

2.0 Materials and Method

2.1 Fabrics

Poly (lactic acid) (PLA) Knitted fabric obtained from Ingeo™ fiber and knitted Polyethylene terepthalate (PET) provided by NatureWorks LLC were used for this work. This investigation used two sets of similarly constructed knitted fabrics obtained from150/144 dtex filament PLA (Ingeo™ fiber) and 150/144 dtex PET filament yarns respectively.

2.2 Dyes

The dye used for this work is Dianix Yellow C-5G 200% (table 2) having chemical name of 1- Ethyl-1, 2- dihydro-6-hydroxy-4-methyl -2-oxo-3-pyridinecarboxamide and molecular formula $C_9H_{12}N_2O_3$. The formular weight is 196.2 and the chemical structure is shown in figure 2 below;

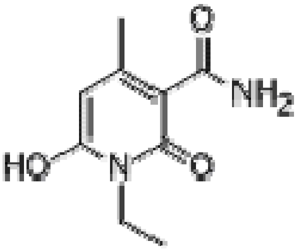

Figure 2: Chemical structure of Dianix Yellow C-5G 200%

Table 2 Selected disperse dye

C.I.Number	Commercial name	Strength	Molecular Weight
Disperse Yellow C-5G	Dianix Yellow C-5G (DyStar)	200%	196.2

2.3. Experimental

2.3.1 Heat-setting Procedure

The heat-setting of knitted PLA and knitted PET fabrics were achieved using the Werner Mathis AG (Textilmaschinen Niederhashi/Zurich) heat-setting equipment. The samples of dimension 200mm by 200mm were held on the sliding aluminum frame at constant-length and heated in dry air at a constant temperature of 130^{o}C which is the maximum temperature for stabilizing PLA as recommended by Cargill Dow. The samples were pinned on the sliding aluminum frame pins and heat set for time durations of 15s, 30s, 45s, 60s, 90s, 120s and 240s respectively. The essence of prolonged heatsetting duration was to comprehend the effect of prolonged heatsetting on knitted PLA and knitted PET fabrics respectively. The PET samples were heatsett at a constant temperature of 180^{o}C. After heatsetting, the fabric samples were allowed to cool down at room temperature for 24 hours. Heat-setting initiates dimensional stability into synthetic fabrics and assists in improving the morphology of the fiber depending on the heat-setting temperature, tension on fabrics, duration of heat-setting and the heat-setting medium.

2.3.2. Scouring Procedure

They heat-setted PLA samples of dimension 200mm by 200mm and total weight of 83g were scoured in 450mls of water using a Mathis LABOMAT Scouring equipment of rpm 55 revs/min for 20 minutes at 60^{o}C in an aqueous solution containing 1.66g/l ERIOPON R, a non ionic detergent and 0.83g/l sodium carbonate (soda ash). This process was carried out at a liquor ratio of 10:1 using a beaker at a continuous stirring. They heat-setted knitted PET samples of total weight 45g were scoured using 450mls water, 1.78g ERIOPON R and 0.83g sodium carbonate at 60^{o}C for 20 minutes in the same equipment. The essence of scouring all knitted fabrics is to extricate all knitting lubricants, oils, waxes, dirt and other forms of impurities before commencing subsequent wet processing operations like dyeing, alkaline clearing and softening. Scouring reduces any propensity for uneven dyeing, stains and dye fastness through the removal of oils, waxes and fats that may abide in the fabric. After scouring, they fabrics were rinsed with cold water and dried at room temperature.

2.3.3. Dyeing of knitted PLA and PET Fabrics

The dyeing properties of PLA, especially in comparison with PET fiber have been intensively studied [19-24]. In this research, dyeing of PLA fabrics subsequently followed scouring, rinsing and drying. This took place at 110^{o}C for 45 minutes using a laboratory scale Mathis LABOMAT Infra-red dyeing machine at a liquor ratio of 10:1 for each of the sample. The pH of the dye bath was maintained at 5 ± 0.1 through the application of acetic acid. 2% of selected disperse dye Dianix Yellow C-5G 200% was used though the quantity applied to each sample was calculated from the percentage weight of the fabric sample numbered from 1 to 7 for easy recognition and assessment. The total dye bath of each sample was also calculated from the weight of the fabric and liquor ratio. Table 3 below shows the individual values as determined from the calculations;

Table 3: PLA dye values

PLA Samples	1	2	3	4	5	6	7
Weight of Samples (g)	11.40	12.00	11.67	11.60	11.50	12.35	8.92
Weight of Dye (g)	0.23	0.24	0.23	0.23	0.23	0.25	0.20
Liquor Ratio	10:1	10:1	10:1	10:1	10:1	10:1	10:1
Total bath (mls)	114	120	117	116	115	124	60

The Mathis LABOMAT Infra-red Uniprogrammer calibrations for the knitted PLA fabric initially read as follows (table 4):

Table 4: Mathis LABOMAT Uniprogrammer Calibrations for PLA

Uniprogrammer Calibrations PLA	Quantities
Rate of Temperature rise	30^{o}C/min
Temperature	110^{o}C
Time	45min
Gradient (Rate of cooling)	5^{o}C/min

Revolution/mm	50 rpm

The Dyeing procedure for PLA as represented by Mathis LABOMAT Infra-red equipment is shown below (figure 3);

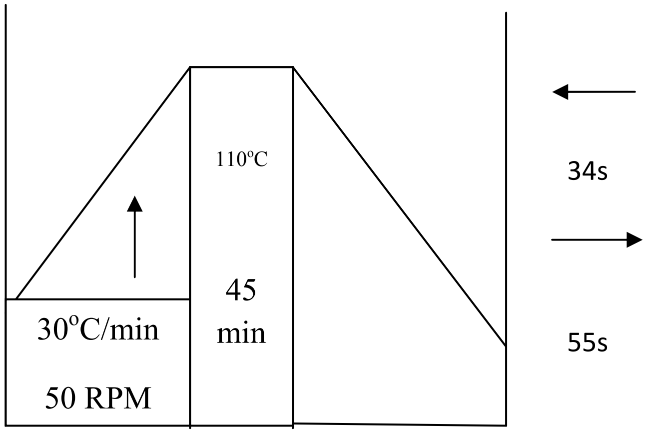

Figure 3: Mathis LABOMAT Uniprogrammer PLA dyeing procedure

The dyeing quantities used in dyeing PET was determined the same method with those of PLA. 2% Dianix Yellow C-5G 200% was also used in dyeing PET at 130°C for 45 minutes using acetic acid to maintain pH at 5±0.1. The equipment used in dyeing was also Mathis LABOMAT infra-red dyeing equipment. The dye quantities as determined are shown in the table 5 below and Mathis LABOMAT Uniprogrammer Calibrations for PET (table 6).

Table 5: PET dye values

PET Samples	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Weight of Fabric (g)	0.08	5.64	6.16	6.15	6.42	6	6.04
Weight of Dye (g)	0.12	0.11	0.12	0.12	0.13	0.12	0.12
Liquor Ratio	10:1	10:1	10:1	10:1	10:1	10:1	10:1
Total Bath (mls)	60.8	56.4	62	62	64.2	60	60

Table 6: Mathis LOBOMAT Uniprogrammer for PET

Mathis LABOMAT Uniprogrammer Calibrations for PET	**Quantities**
Start Temperature	20°C
Solution Temperature	20°C
Gradient	3°C/min
RPM	50rpm

After dyeing, the PET fabrics were rinsed for 5 minutes using warm water and 2 minutes using cold water and subsequently dried at room temperature. A schematic representation of the dyeing procedure used for PLA and PET in this study is shown figures 4 and 5 below;

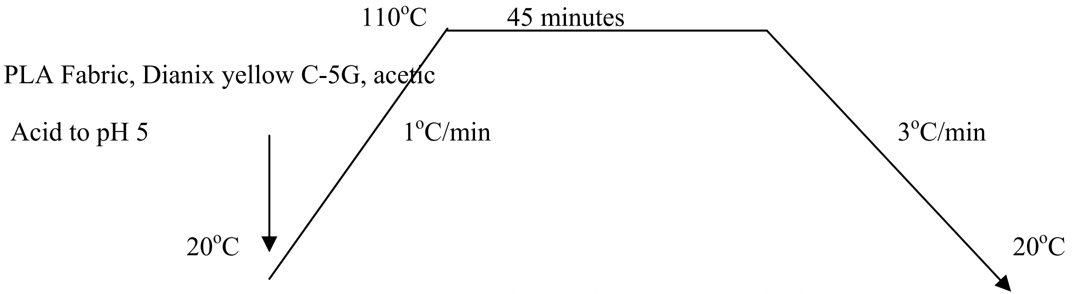

Figure 4: Procedure of disperse dye applied to PLA

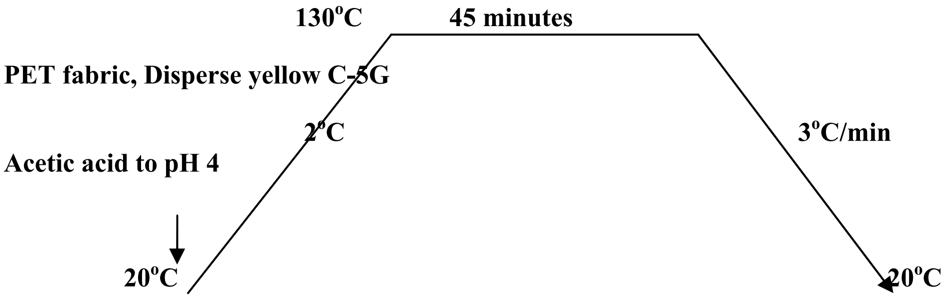

Figure 5: Procedure of disperse dye applied to PET

2.3.4 Alkaline reduction clearing procedure

Alkaline reduction clearing is a process which occurs after dyeing and air drying in order to extricate surface disperse dye [25-27]. All the samples used for this study were subjected to the same alkaline reduction clearing procedure. The quantities of chemicals used were calculated from a combination of the total weight of PLA and PET samples. The quantities are shown in table 7 below:

Table 7: Alkaline Clearing Parameters

PARAMETERS	QUANTITIES
Total weight of all samples	122.7g
Sodium Hydroxide	12g
Sodium dithionite	6g
Warm water	2 Liters
Temperature of plate	70°C-80°C
Time	10-20 minutes

From the above table, alkaline reduction clearing of both Knitted PLA and PET samples occurred within 70°C to 80°C for duration of 10-20 minutes. 6g of Sodium dithionite and 12g of sodium hydroxide were used to create enabling alkaline conditions needed for clearing to take place and for accurate comparative analysis. The efficiency of alkaline reduction clearing is a function of the chemical structure of the disperse dye [28-33]. When disperse dyes are treated with reducing agents, due to their azo group content, they are sensitive to treatment with a reducing agent usually in form of alkaline solution of sodium dithionite (hydros). The reducing agent destroys the azo chromophore, resulting to a loss of its color through the splitting of the azo chromophore into two colorless amino compounds [34-37] as shown in the equation below:

Alkaline reduction:

$$\underset{\text{Colored}}{R_1 - N = N - R_2} \xrightarrow[\text{[H]}]{} \underset{\text{Colorless}}{R_1 - NH_2 + NH_2 - R_2}$$

Dye decolorization during alkaline reduction clearing process

They softening agents used in softening the PLA and PET fabrics were Ciba® Sapamine® HS and Siligen CSM which were applied on the samples through padding using the Werner Mathis AG padding equipment (Figure 6) calibrated at a pressure of 2 bar and roller speed of 2.5m/min. The time of padding was 2 minutes at a temperature of 30 to 40^{o}C. The two softeners were combined at 30g/l whereby 3mls of each were mixed with 200mls of water to affect the softening process. The liquor ratio was 10:1 at a pH of within 5 – 6 sustained through the use of acetic acid. The liquor pick-up was about 90%. Ciba Sapamine is chemical composed of fatty acid ester, silicone, emulsion of fatty acid amide and polyalkylene. It is non – ionic/cationic in character with a pH of 4-5.5. Siligen® CSM is a hydrophilic silicone – based softener, a registered trademark of BASF, composed of wax, polysiloxanes and non-ionic surfactants.

After the padding process, the softened PLA and PET fabrics were subjected to a drying procedure at a temperature of 110^{o}C in 2 minutes using Werner Mathis AG equipment (figure 6). The fabrics were then kept for storage for 7 days at room temperature and atmospheric pressure.

Figure 6: Werner Mathis AG padding (softening) equipment

2.3.5 The Kawabata Evaluation System

The KES-FB system (figure 7) determines fabric properties at small loads equivalent to those the fabrics are subjected to at normal end use application. The tensile properties determined were fabric extension [%], linearity of load extension, tensile energy [WT] g.cm/cm^2 and tensile resilience [%]. The specimen were clamped between two chucks each of 20cm long. A constant force of 200g was applied by attachinga weight to the front chuck of the specimen. When the test started, the back chuck constantly slided initially right to an angle of 8^o then back to it's original position.

Figure 7: KES FB 1 Tensile equipment

3.0 Results AND Discussion

3.1 Fabric extension (%)

The results of measurement for fabric extension [%] in warp and weft direction are shown below (table 8):

Table 8: Extension EM [%]

Time of heatsetting [Sec]	PLA warp extension EM [%]	PET warp extension EM [%]
15	14.3	6.77
30	11.83	6.7
45	10.60	7.92
60	10.04	6.94
90	17.73	8.01
120	15.10	7.35
240	9.77	6.61

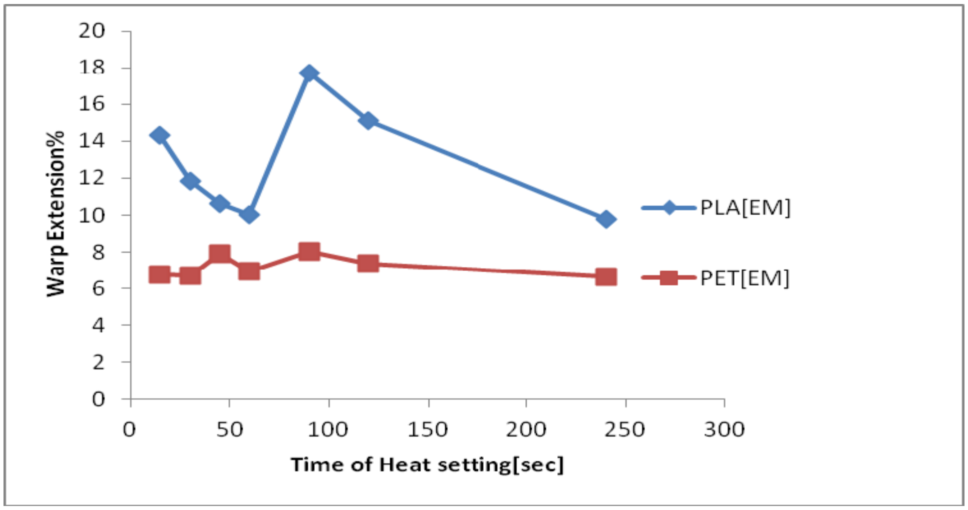

Figure 8: Effect of increasing time of Heat setting and wet processing on knitted PLA and PET Warp Extension EM [%]

Figure 8 shows the effect of increasing time of heatsetting and various wet treatments or finishing processes on the warp extension. Knitted PLA exhibited a higher extension in warp direction generally though dramatic increases in extension occurred for both fabrics with increase in time of heat setting. This implies that knitted PLA exhibits a higher degree of softness, flexibility and smoothness than PET with increasing time of heatstting.

The table below (table 9) shows the measurements for Extension EM [%] in Weft direction for PLA and PET knitted fabrics:

Table 9: Extension EM [%] in weft direction for knitted PLA and PET

Time of heatsetting [Sec]	PLA weft extension EM [%]	PET Weft extension EM [%]
15	14.13	9.91
30	12.37	10.40
45	13.97	10.16
60	16.70	9.28
90	15.13	16.93
120	15.13	9.13
240	12.73	11.73

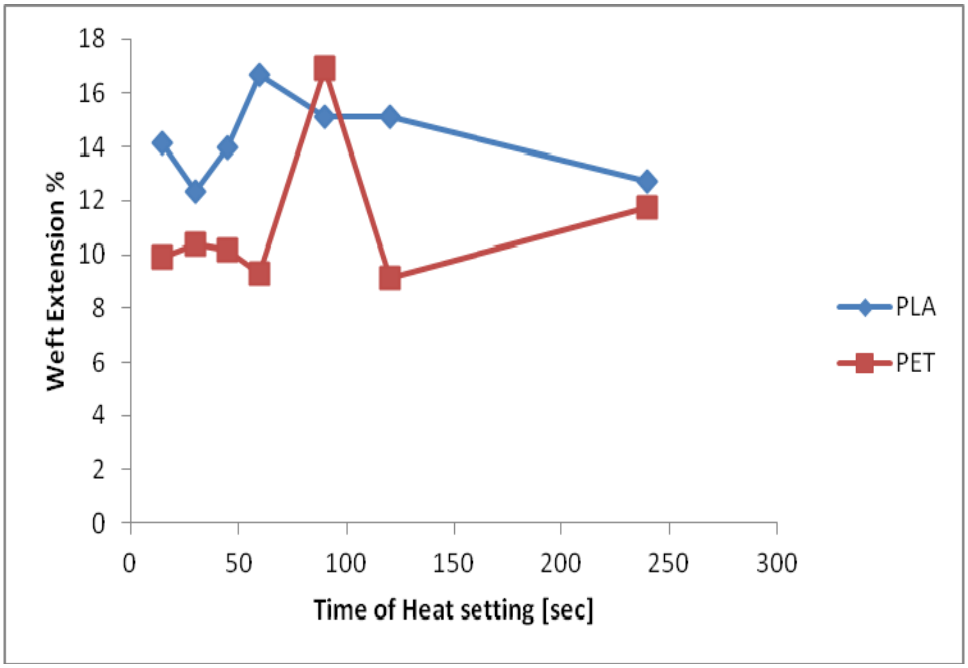

Figure 9: Effect of varying time of heat setting and wet processing on weft Extension EM[%] of knitted PLA and PET fabric

Figure 9 shows the effect of increasing time of heat settting and wet or finishing treatments to the weft extension [EM] % of both knitted PLA and PET. The figure implies that PLA exhibited increased weft extension with increasing time of heat setting up to about 60s with a remarkable change in behaviour.

The mean value [Ā] of both warp and weft direction are shown in table 10 below:

Table 10: Mean Extension EM [%] Ā

Time of Heat Setting [Sec]	PLA [mean]	PET [mean] Ā
15	14.38	8.34
30	12.10	8.55
45	12.28	9.04
60	13.37	8.11
90	16.43	12.47
120	15.12	8.24
240	11.25	9.17

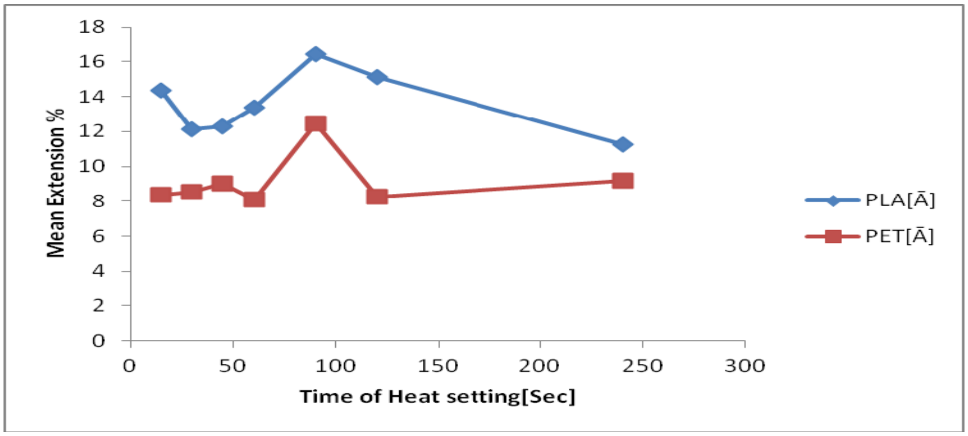

Figure 10: Effect of varying time of heat setting and wet processing on mean value of warp and weft direction

Figures 8, 9, and 10 show that knitted PLA exhibits a higher Extensibility in both warp and weft direction when subjected to KES-FB Extension EM [%] test. This is confirmed by the PLA and PET plots and the mean plots also show that knitted PLA fabric exhibits greater Extension EM % in both warp and weft direction than knitted PET fabric. Generally, very low warp/weft extensibility could result in overfeeding difficulty in warp/weft direction during making up. Seam pucker may occur may occur in the low extensibility direction and garment discomfort. Also if a fabric is too extensible, it may result to difficulties in laying/cutting, shape retention, pattern matching and creating fullness. High fabric extensibility enhances fabric hand (softness) and increased formability.

3.2 Linearity of Load-Extension curve LT [-]

This parameter measures the deviation of the load-extension curve from a straight line. The mean value [LT] is usually used. Results were obtained in warp and weft direction and the mean value derived from the two.

The value for the LT values for PLA and PET in warp and weft directions are shown in tables 11 and 12 respectively.

Table 11: PLA and PET linearity of load – extension curve values for warp direction

Time of Heatsetting [sec]	PLA warp [LT]	PET warp [LT]
15	0.963	0.982
30	0.787	0.999
45	0.882	0.899
60	0.903	0.918
90	0.787	0.866
120	0.820	0.846
240	0.915	0.912

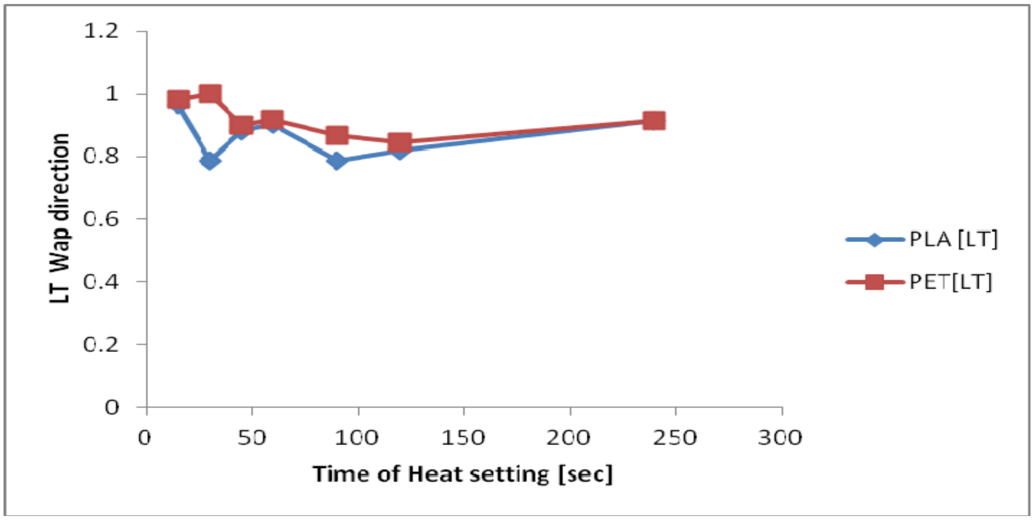

Figure 11: Effect of varying time of heat setting and wet processing on LT for PLA and PET in warp direction

Table 12: PLA and PET linearity of load – extension [LT] values for weft direction

Time of heat setting[sec]	PLA weft [LT]	PET weft [LT]
15	0.915	0.982
30	O.935	0.975
45	0.865	0.951
60	0.828	0.957
90	0.775	0.701
120	0.783	0.935
240	0.925	0.868

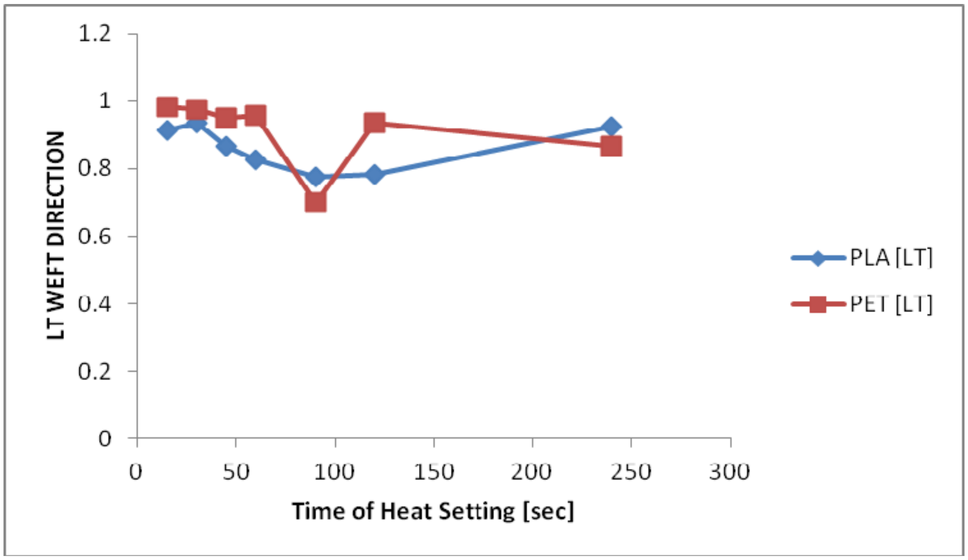

Figure 12: Effect of varying time of heat setting and wet processing on PLA/PET in weft direction

The mean values of LT are most acceptable in evaluating LT for KES-FB System and results obtained are shown below (table 13);

Table 13: Mean values for linearity of load –extension for PLA and PET

Time of Heat Setting [sec]	PLA [LT] mean	PET [LT] mean
15	0.883	0.982
30	0.861	0.987
45	0.873	0.925
60	0.865	0.938
90	0.781	0.783
120	0.801	0.891
240	0.920	0.890

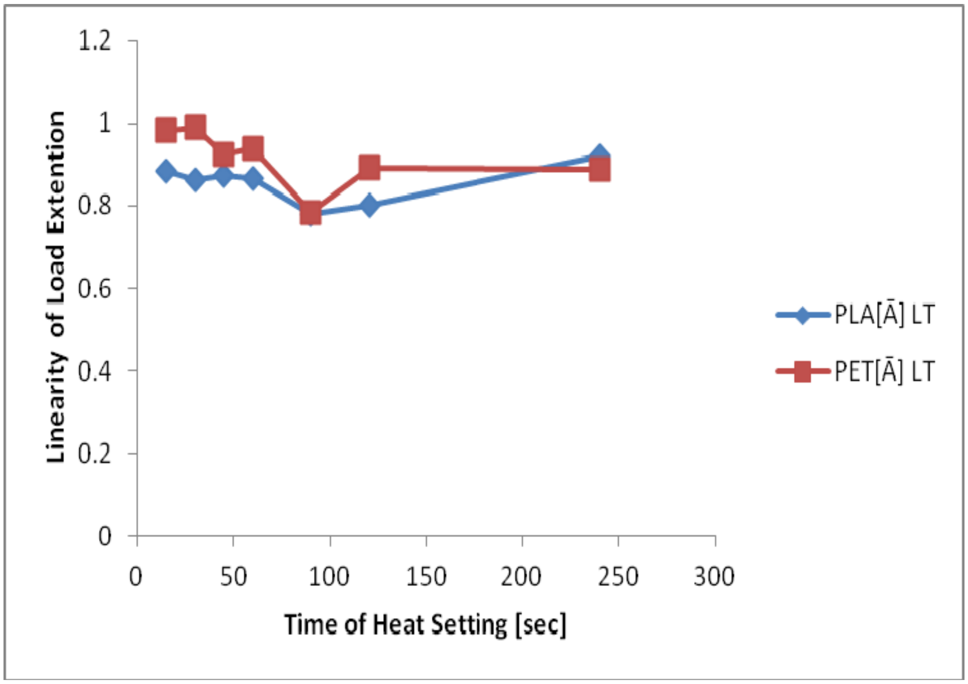

Figure 13: Effect of varying time of heat setting on linear load extension [LT] for PLA/PET

From figure 13 above, it appears knitted PET has a higher linearity of load extension than knitted PLA. This shows that knitted PLA has a smaller LT than PET indicating PLA exhibits a softer hand with the implication of showing a larger extension in the initial low load region of the load extension curve. PLA exhibiting lower LT values implies better formability as extensionsibility under small loads represents in-plane compressibility which is proportional to formability. PET exhibiting higher LT shows a more elastic and stiffer fabric meaning a lower formability. In both the warp (figure 11) and weft (figure 12) direction, PET exhibited a slightly higher LT orientation. With increasing temperature of heatsetting, LT of PET was high at 15s but reduced at 240s. Thus, ultimately there is a reduction in LT values in both warp and weft direction with increasing time of heat setting.

3.3 Tensile energy, WT [gf.cm/cm^2]

Tensile Energy WT [gf.cm/cm^2] is another important parameter measured for knitted PLA and PET using the Kawabata Evaluation system for fabrics. This is the energy required to extend a fabric to a prefixed maximum load. The results obtained from this test are shown below (table 14);

Table 14: Tensile energy W in warp direction for PLA and PET

Time of heatsetting [sec]	PLA warp WT [g.cm/cm^2]	PET warp WT [g.cm/cm^2]
15	3.11	1.66
30	2.33	1.67
45	2.33	1.78
60	2.26	1.59
90	3.49	1.73
120	3.09	1.55
240	2.23	1.51

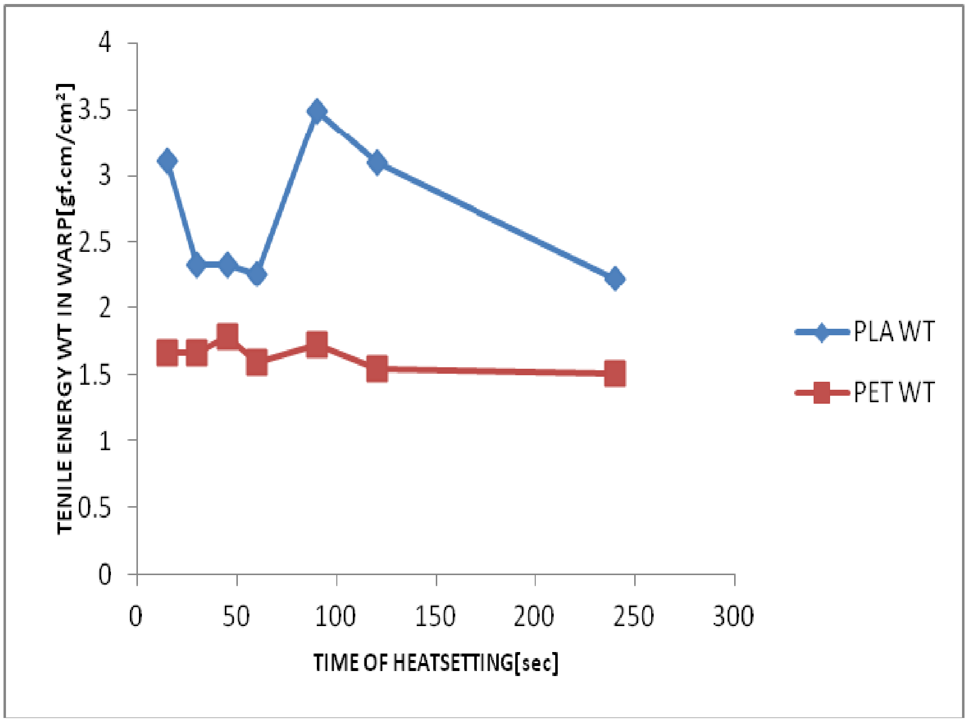

Figure 14: Effect of varying time of heatsetting and wet processing on the Tensile Energy of PLA and PET in **warp direction**

The results obtained from the Kawabata for Tensile energy W in weft direction for PLA and PET is shown below (table 15)**:**

Table 15: Tensile energy WT for PLA in weft direction for PLA and PET

Time of heatsetting [sec]	PLA weft WT [gf.cm/cm^2]	PET weft WT [gf.cm/cm^2]
15	3.19	2.43
30	2.89	2.53
45	3.01	2.41
60	3.45	2.22
90	2.93	2.97
120	2.96	2.13
240	2.94	2.55

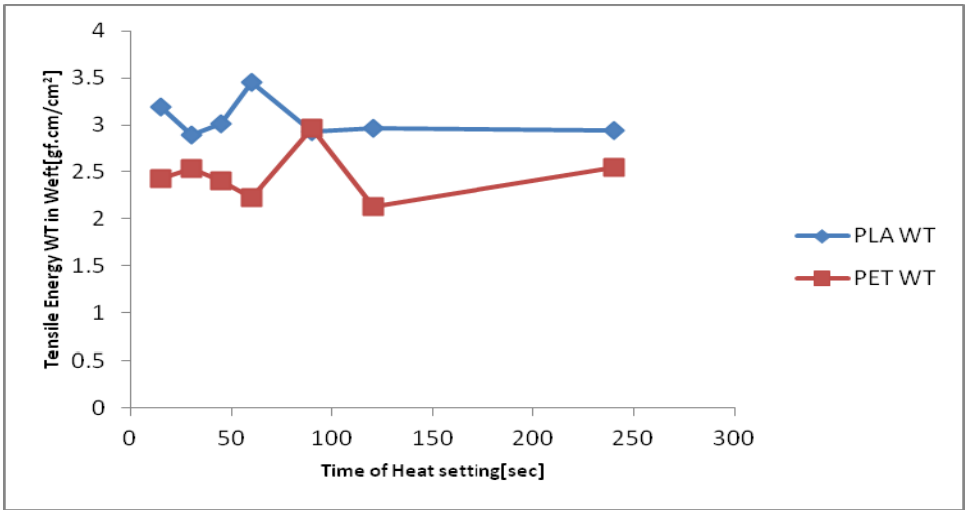

Figure 15: Effect of Heat setting and wet processing on the tensile energy WT of PLA and PET in weft direction

The average value or mean [Ā] of the Tensile Energy WT [gf.cm/cm^{-2}] is usually used in characterizing the fabric. The Tensile Energy WT mean [Ā] values obtained from the weft and warp direction of the KES-FB test are shown below (table 16):

Table 16: Mean [Ā] of tensile energy values of PLA and PET in weft and warp directions

Time of heatsetting [Sec]	PLA WT mean [Ā]	PET WT mean [Ā]
15	3.15	2.05
30	2.61	2.10
45	2.67	2.10
60	2.86	1.91
90	3.21	2.35
120	3.03	1.84
240	2.59	2.03

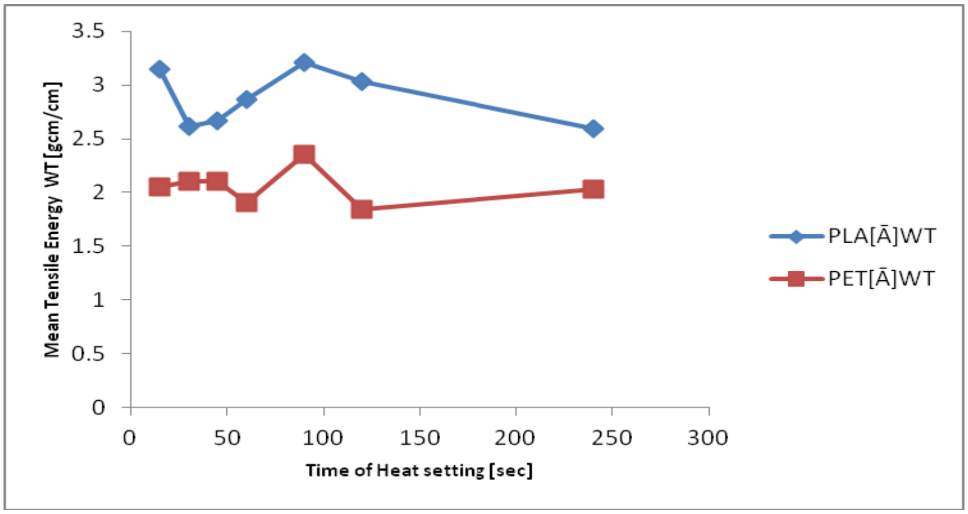

Figure 16: Effect of varying time of Heat setting on the Tensile Energy WT of PLA and PET

Figures 14-16 above appear to show that with increasing time of heat setting on PLA and PET, the PLA tensile energy is higher than the PET tensile energy. The implication of this result is that PLA has a higher Tensile Energy than PET knitted fabric both in warp and weft directions. A higher WT means a higher extensibility. Hence PLA has a higher extensibility than PET in both warp and weft direction. The WT of PLA and PET is closely related to flexibility, softness, gentleness and smoothness and this infers that PLA showing a higher orientation may exhibit higher flexibility, softness, gentleness and smoothness in comparison to PET knitted fabric.

3.4 Tensile Resilience RT [%]

Tensile resilience, RT [%] is the ability of the fabric to recover from extension when the force is removed. Higher values of tensile resilience imply that the fabric has a higher ability to recover from stretch. The mean values are normally used in characterizing the fabrics. The tensile resilience values obtained from the heatsett and finished samples in warp, weft and mean positions are shown in tables 17-19 respectively below:

Table 17: Tensile Resilience RT in warp direction for PLA and PET

Time of Heatsetting[sec]	PLA warp[RT] %	PET warp [RT] %
15	58.05	61.87
30	53.44	61.01
45	56.71	59.97
60	54.73	70.35
90	55.41	70.47
120	51.83	65.77
240	56.89	71.30

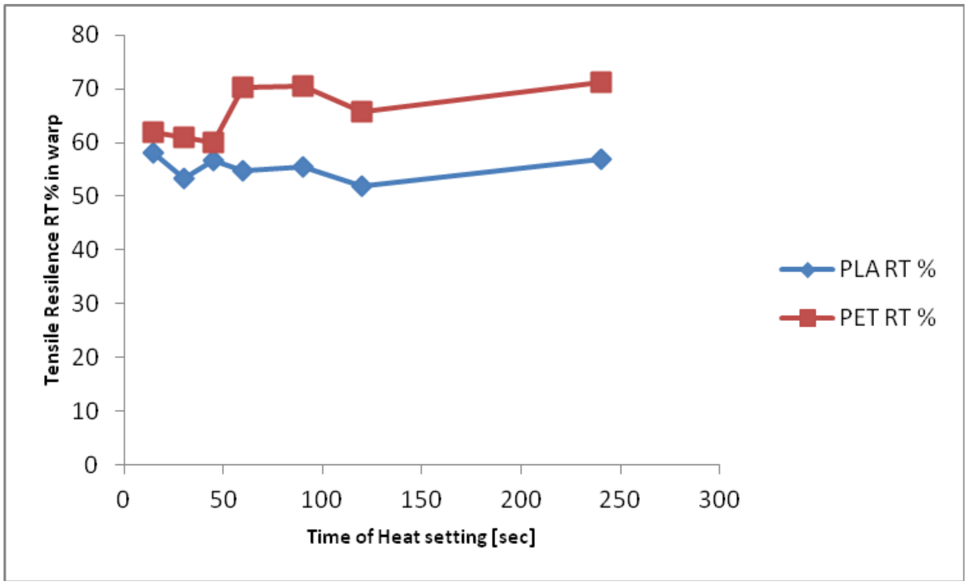

Figure 17: Effect of heatsetting and finishing processes on tensile resilience RT [%] of PLA and PET in warp direction

Figure 17 shows the effect of increasing time of heat setting and wet processing on the tensile resilience [RT] % of PLA and PET in warp direction. Knitted PET fabric generally exhibited a higher tensile resilience in warp direction than PET knitted fabric. This implies that with increasing time of heatsetting PET tends to be stiffer than PLA. This shows that PLA is softer than PET with increasing time of heatsetting. Just like in warp direction, knitted PET displayed a higher tensile resilience than PLA in weft direction (see figure 18 below).

Table 18: Tensile resilience RT [%] for knitted PLA and PET in weft direction

Time of heatsetting[sec]	PLA [RT] % in weft	PET [RT] % in weft
15	44.71	66.36
30	51.19	66.37
45	47.22	67.15
60	48.77	76.94
90	44.57	78.43
120	45.90	75.97
240	50.22	77.25

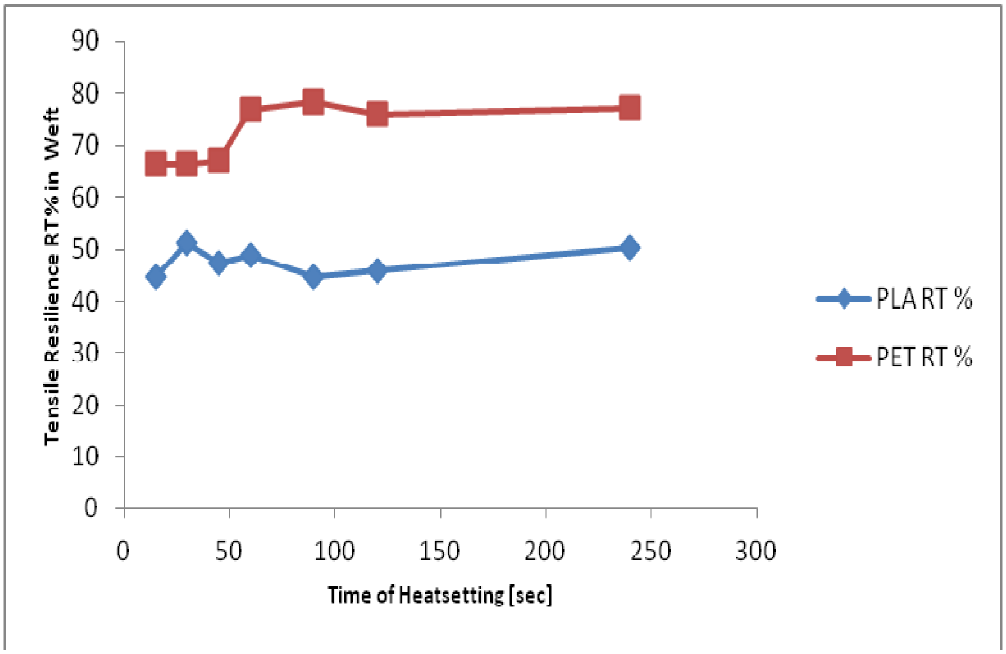

Figure 18: Effect of Heat setting and wet processing on Tensile Resilience RT % of PLA and PET weft direction

The average or mean[Ā] value of the weft and warp values are used in characterizing the tensile resilience RT properties. The mean results are shown below (table 19):

Table 19: Tensile Resilience [RT] % mean values for PLA and PET knitted fabrics

Time of heatsetting	PLA[RT]% mean	PET[RT]% mean
15	51.38	64.12
30	52.31	63.69
45	51.97	63.56
60	51.75	73.65
90	49.99	74.45
120	48.86	70.87
240	53.55	74.27

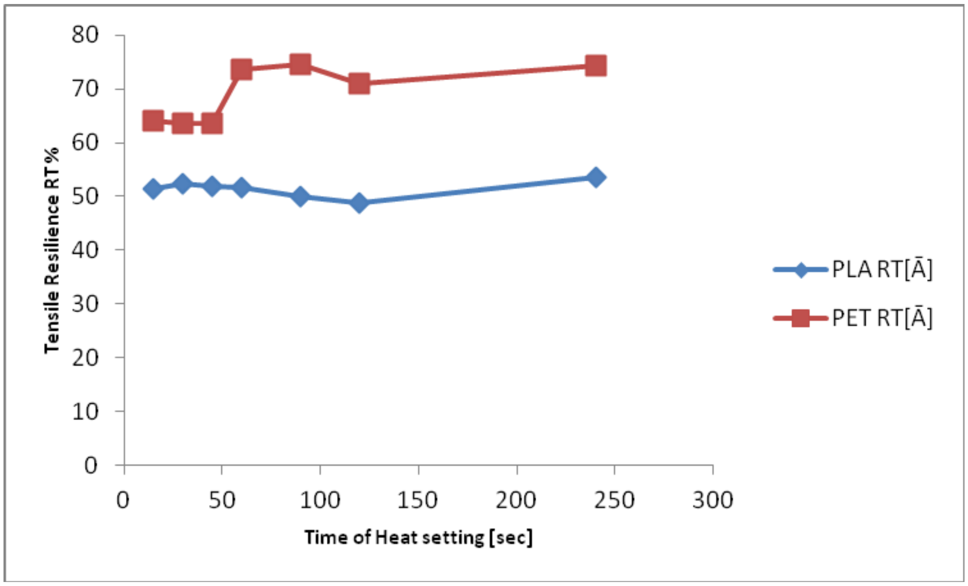

Figure 19: Effect of heatsetting on the tensile resilience RT % of knitted PLA and PET fabrics

From figures 17-19 above, Knitted PET fabrics have higher tensile resilience when compared to knitted PLA fabrics. A lower tensile resilience as possessed by knitted PLA over knitted PET infers a higher softness and flexibility as a lower RT often correlates to a higher EM which is related to softness. But a too low RT values adversely affect garment appearance. RT increases in fabrics as inter fiber forces are reduced. Too high or too low RT may result in difficulty in overfeeding and cutting.

4.0 Conclusion

PLA exhibited a consistent increase in tensile extension over PET for the same time of heatsetting and wet finishing applications. This implies that PLA may tend to exhibit enhanced fabric hand or softness and increased formability than PET. There is a remarkable change on the tensile extension [EMT] of both fabrics. This is because finishing processes generally tends to alter fabric properties.

A smaller LT indicates a softer hand [larger extension in the initial low load region of the load extension curve. Subjectively PLA fabric stretch is linked closely to LT [initial resistance to tension] and RT [resilience]. PLA exhibition of lower LT with increasing time of heatsetting and various wet treatments implies a better formability as extensibility under small load represents in–plane compressibility which is equivalent to fabric formability. Fabric tailorability generally improves with improved fabric formability.

PLA consistently increased in tensile energy over PET. Tensile energy [WT] g.cm/cm^2 is the energy required to extend a fabric to the prefixed maximum load and closely related to fabric flexibility, softness, gentleness and smoothness. Hence, it can be concluded that knitted PLA fabric exhibited increased tensile energy equivalent to improved softness, gentleness, and smoothness over PET for same heatsetting processes and finishing. Higher crimp level in the structure will increase fabric extensibility.

Tensile resilience, RT % is a measure of the ability of a fabric to recover after extension when the applied force is removed. A higher value implies a stretchier material. PET is a stretchier material than PLA whether in untreated and treated form. A lower RT promotes softness and RT increases in fabric finishing as the inter fiber forces are reduced. This implies that PLA exhibiting a lower RT tend to be softer than PET.

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