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Effects of time of heatsetting on the tensile properties of ingeo™ poly (lactic acid) (PLA) fabric

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Abstract
Poly (lactic acid) is biodegradable and environmentally benign aliphatic polyester produced from the fermentation of naturally occurring and renewable resources like corn, sugar and vegetables and subsequently converted to a textile fiber through melt spinning and spun bonding. A study of the effect of time of heatsetting on tensile properties of knitted Ingeo™ Poly (lactic acid) fabric was investigated and reported in this paper. PLA samples were subjected to increasing heatsetting times of 15s, 30s, 40s, 60s, 90s and 240s at 130^{0}C using the Werner Mathis Infra red heatsetting equipment. Tensile properties were evaluated using the KES-FB (KAWABATA) fabric evaluation system. The tensile properties determined in weft and warp directions included fabric extension [%], linearity of load extension [-], tensile energy [WT] g.cm/cm^2 and tensile resilience [%]. Results revealed the optimum time of heatsetting PLA yarns to attain dimensional stability was within the time range of 30-45s at heatsetting temperature of 130 ^{0}C.

Keywords: Ingeo™ poly (lactic acid); Heatsetting; Tensile properties; KES-FB (KAWABATA); Evaluation system; Fabric extension [%]; Linearity of load extension; Tensile energy (WT) g.cm/cm^2; Tensile resilience [%].

1. Introduction
Ingeo Poly (lactic acid) fiber is wholly produced from annually renewable raw material source that is not oil**.** The raw materials used in the production of Ingeo PLA include corn, sugar and vegetables [1]. Ingeo is Cargill Dow's brand name for the first man made fiber derived from 100% annually renewable resources [2]. The process starts with corn, an abundant raw material that can easily and efficiently be converted into plane sugars which subsequently undergo fermentation (see figure 1). The fermentation products are immediately transformed into high performance polymer called polylactide from which the branded Ingeo fibers and filaments are extruded [1, 2]. Production of PLA is achieved by two major routes through the direct condensation polymerization reaction of lactic acid and ring opening polymerization of lactic acid yielding poly (lactic acid) or poly (d, l-lactic) acid depending on lactic acid isomers used [4-6]. Poly (lactic acid) can be produced by melt and solution spinning [3, 4, 13, 14] though the former is used more regularly due to its more eco friendliness and ease of processing. The Processability of PLA is equivalent to that of petroleum based synthetic material where polymer uses conventional polyester type fiber melt spinning processes. PLA [$(C_3H_4O_2)_n$] is the first melt processable

natural based fiber. It is a synthetic polymer based on lactic acid ($C_3H_6O_3$) and produced from the fermentation of agricultural resources such as corn [7, 8] and compostable as it easily degrades by simple hydrolysis under appropriate conditions.

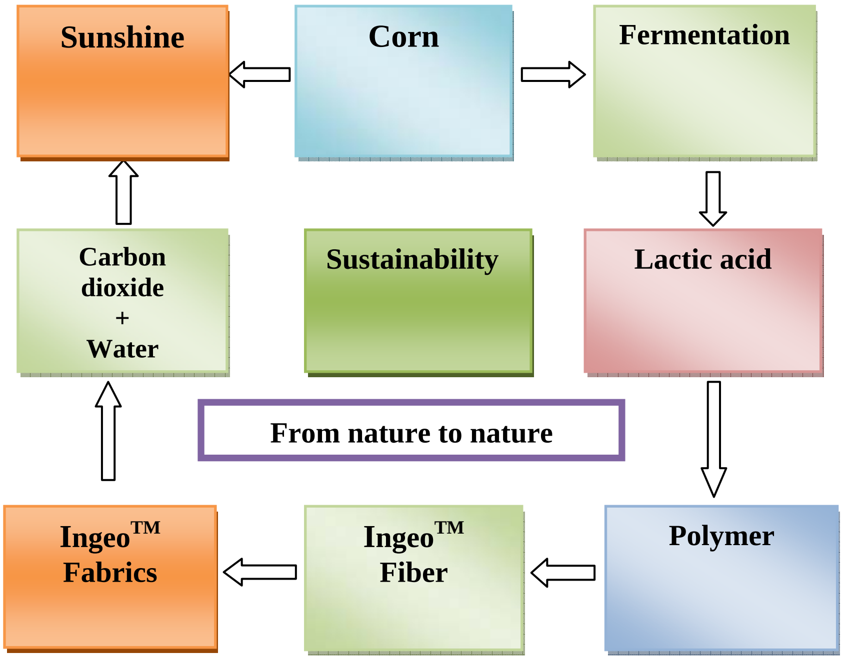

Figure 1. Production cycle of Ingeo™

Cargill Dow developed a patented and minimal cost continuous process for the production of PLA polymer. The process begins with the continuous condensation of lactic acid to form a low molecular weight PLA pre polymer [12, 15] which is converted to a mixture of lactide stereo isomers using catalysis to enhance the rate and selectivity of the intra molecular cyclisation reaction [5]. The molten lactide mixture is subsequently purified through vacuum distillation. Tin catalyst is then utilized to produce high molecular weight PLA polymer, ring opening polymerization in the melt and completely eliminating the use of costly and non-ecofriendly solvents. On completion of the polymerization process, the remaining monomer is removed by vacuum and recycled back to the beginning of the process [16].
PLA can be melt spun into different types of fibers including monofilaments, multi filaments, bulked continuous filament staple fibers, short-cut fibers and spun bond fabrics by conventional melt spinning machines [17]. The fibers are then drawn and annealed to give desirable mechanical properties such as high tenacity, good toughness and dimensional stability [7-10].
Through the control of D- and L- isomers in the PLA polymer chain, there is the possibility of inducing different crystalline melting points into the PLA chain [11]. Heatsetting the fibers thus introduce enhanced dimensional stability to the fibers improving fiber morphology and orientation. The heatsetting process is determined by temperature, time of heatsetting (air, solvent or water) and the tension applied to the substrates during heatsetting [11, 12].
The essence of this paper is to determine the effect of time of heatsetting on the tensile properties of Knitted PLA fabrics. Knitted PLA fibers are dyeable using disperse dyes at temperatures not exceeding 130^{o}C. PLA fibers can be dyed with disperse dyes like DENAPLA, Nagase Colors & Chemicals Co., Ltd, Japan at lower temperature, 100-110^{O}C [18]. It is recommended that PLA fibers should not be dyed at temperatures as high as 120^{O}C, because PLA is more prone to hydrolysis at high temperature and humidity, particularly under alkaline conditions, than PET.

2. Materials and method

The Ingeo Poly (lactic acid) fabric used for this investigation was supplied by Nature Works LLC, USA. Sixteen samples of ‘pique’ knitted fabrics obtained from 150/144 dtex/ filament PLA were used for this study. These samples were subjected to heatsetting times of 15s, 30s, 45s, 60s, 90s, 120s and 240s at 130^{o}C. The KES-FB system (Figure 2) was used in determining four tensile properties including fabric extension in %, linearity of load extension, tensile energy [WT] g.cm/cm^2 and tensile resilience [%]. The instrument used was the tensile and shear tester [model KES-FB 1].

2.1 Experimental

The heatsetting of knitted PLA was achieved using the werner mathis AG (Textilmaschinen Niederhashi Zurich) (Figure 3). The samples of dimension 200mm by 200mm were held on the sliding aluminium frame at constant-length and heated in dry air at 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 and heatsetted at 15s, 30s, 45s, 60s, 90s, 120s and 240s respectively.

The KES-FB system 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 2. KES-FB 1 tensile tester

Figure 3. Werner mathis AG heatsetter

3. Results and discussion

3.1 Fabric extension EM (%)

Fabric Extension EM (%) is represented by Table 1. Figures 4 and 5 show the effect of time of heatsetting on knitted Ingeo™ Poly (lactic acid) (PLA) fabric. This implies that maximum extension in warp direction occurred at 60s and 90s at 130^{o}C and increasing time of heatsetting up to 240s decreased weft extension and impacted negatively on commercial success of the fabric. This implies that PLA exhibited a higher degree of softness; flexibility and smoothness at heatsetting time of 60s and further heatsetting does not add value to the fabric.

Table 1. Fabric extension EM [%]

Time of Heatsetting [s]	PLA Warp Extension [%]	PLA Weft Extension [%]	Mean Extension [%]
15	14.3	14.13	14.38
30	11.83	12.37	12.10
45	10.60	13.97	12.28
60	10.04	16.70	13.37
90	17.73	15.13	16.43
120	15.10	15.13	15.12
240	9.77	12.73	11.25

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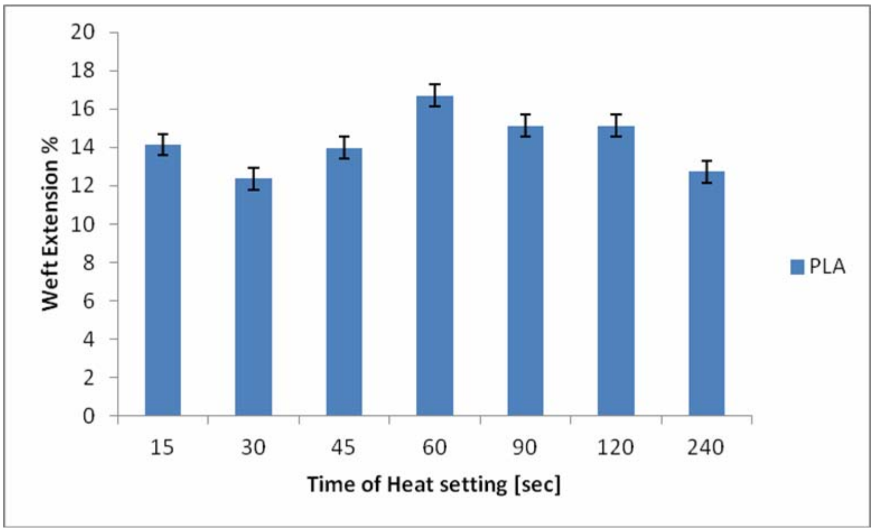

Figure 4. Effect of time of heatsetting on the tensile Extension EM [%] in Weft direction of knitted Ingeo™ Poly (lactic acid) [PLA]

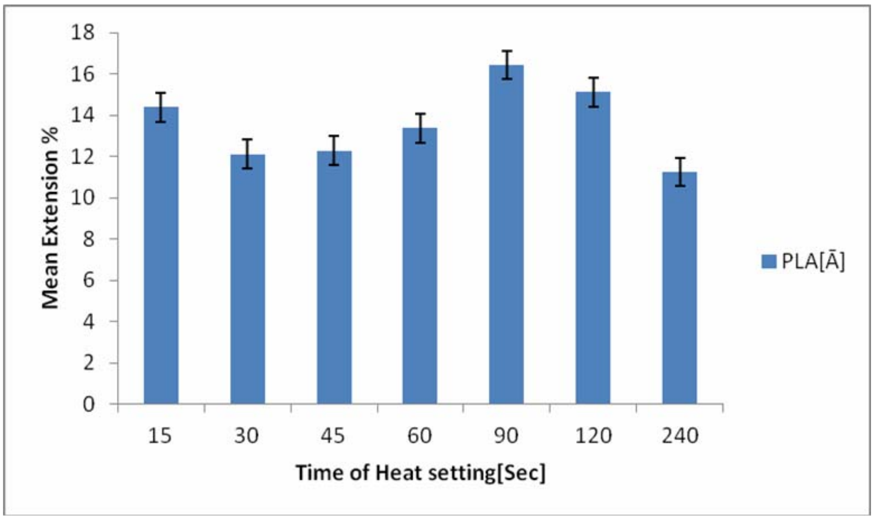

Figure 5. Mean [Ā] of effect of time of heatsetting on the tensile extension EM [%] of Ingeo™ Poly (lactic acid)

3.2 Linearity of load extension curve LT [-]

The linearity of load extension curve is displayed by Table 2. Figures 6, 7 and 8 below show the effect of heatsetting on linearity of load extension. Though not very significant on overall fabric property, increasing time of heatsetting on PLA implied that PLA exhibited a larger extension in the initial low load region of the load extension curve. Lower LT as shown by PLA implies better formability as extensibility under small loads represents in-plane compressibility which is proportional to formability.

Table 2. Linearity of load extension curve LT [-]

Time of heatsetting [s]	LT Warp	LT Weft	LT Mean
15	0.963	0.915	0.883
30	0.787	0.935	0.861
45	0.882	0.865	0.873
60	0.903	0.828	0.865
90	0.787	0.775	0.781
120	0.820	0.783	0.801
240	0.915	0.925	0.920

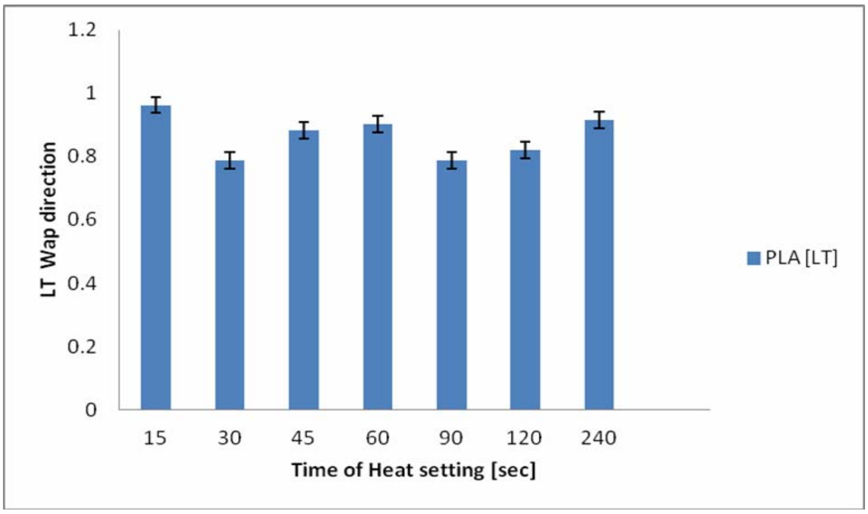

Figure 6. Effect of time of heatsetting on the linearity of load extension in warp direction of knitted Ingeo™ Poly (lactic acid) fabric

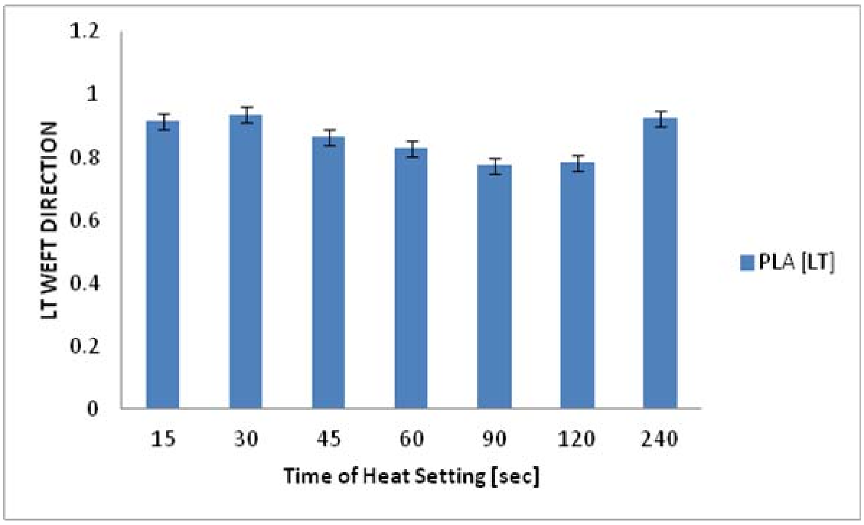

Figure 7. Effect of time of heatsetting on the linearity of load extension in weft direction of knitted Ingeo™ Poly (lactic acid)

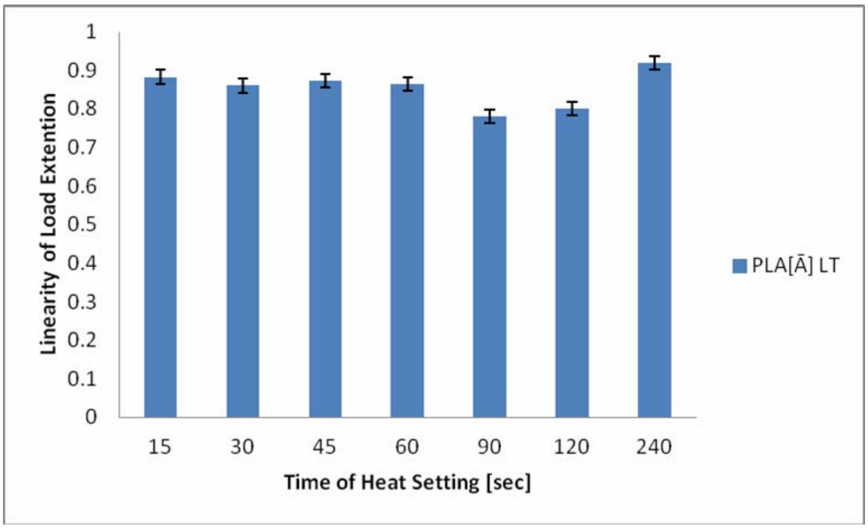

Figure 8. Mean effect of time of heatsetting on the linearity of load extension LT of knitted Ingeo™ Poly (lactic acid) (PLA) fabric

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

Tensile energy, WT [gf.cm/cm^2] determined the energy required to extend a fabric to a prefixed maximum load. Table 3 shows the results obtained using the KES-FB system of testing. Figures 9, 10 and 11 show the effect of time of heatsetting on tensile energy in warp and weft direction and the mean effect. From the figures it can be deduced that optimum effect of heatsetting on tensile energy is obtained within 30s to 90s. A higher WT implies a higher extensibility and closely related to flexibility, softness and smoothness.

Table 3. Tensile energy in warp, weft and mean

Time of heatsetting[s]	WT Warp[g.cm/cm^2]	WT Weft[g.cm/cm^2]	WT [g.cm/cm^2] Mean
15	3.11	3.19	3.15
30	2.33	2.89	2.61
45	2.33	3.01	2.67
60	2.26	3.45	2.86
90	3.49	2.93	3.21
120	3.09	2.96	3.03
240	2.23	2.94	2.59

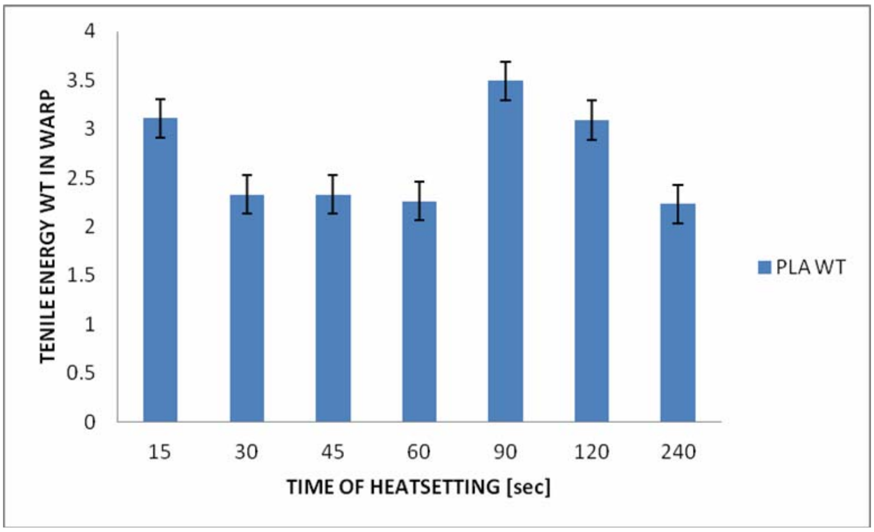

Figure 9. Effect of time of heatsetting on tensile energy WT g.cm/cm^2 in warp direction of knitted Ingeo Poly (lactic acid) fabric

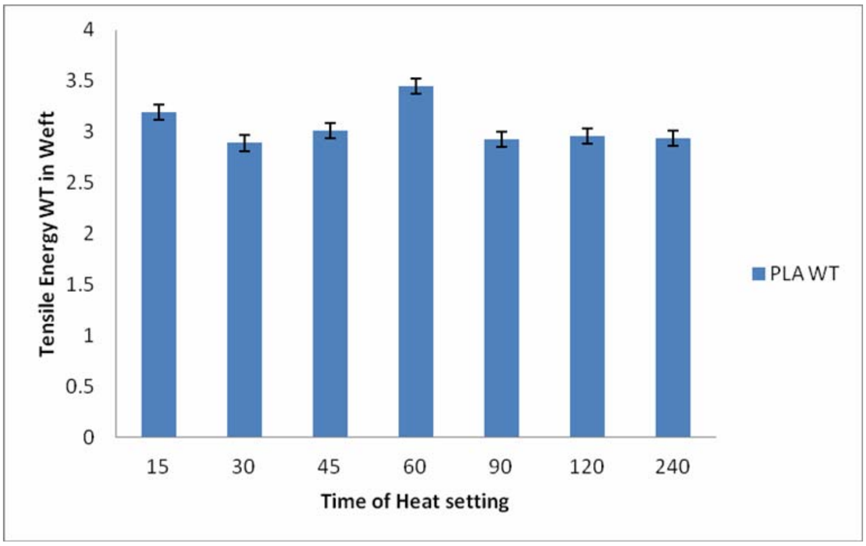

Figure 10. Effect of time of heatsetting on tensile energy WT g.cm/cm^2 in weft direction

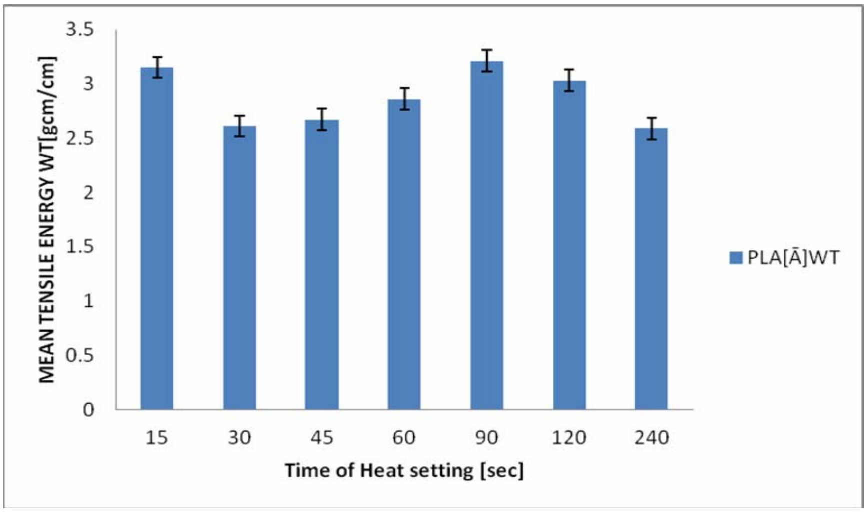

Figure 11. Mean effect of time of heatsetting on tensile energy WT g.cm/cm^2 of knitted Ingeo Polylactic acid fabric

3.4 Tensile resilience RT [%]

Tensile Resilience RT [%] is the ability of the fabric to recover from extension when applied force is removed. Table 4 shows the result for the effect of time of heatsetting on tensile resilience in warp and weft direction and the mean effect.

Figures 12, 13 and 14 show the effect of time of heatsetting on tensile resilience of knitted Ingeo PLA fabric. From the results it can be deduced that PLA possess a lower tensile resilience inferring a higher softness and flexibility. Increasing time of heatsetting does not show a remarkable difference in tensile resilience of knitted Ingeo PLA fabric. A lower RT correlates to a higher EM which is related to softness.

Table 4. Tensile resilience in warp, weft and mean

Time of heatsetting[s]	PLA Warp[RT] %	PLA Weft[RT] %	PLA Mean
15	58.05	44.71	51.38
30	53.44	51.19	52.31
45	56.71	47.22	51.97
60	54.73	48.77	51.75
90	55.41	44.57	49.99
120	51.83	45.90	48.86
240	56.89	50.22	53.55

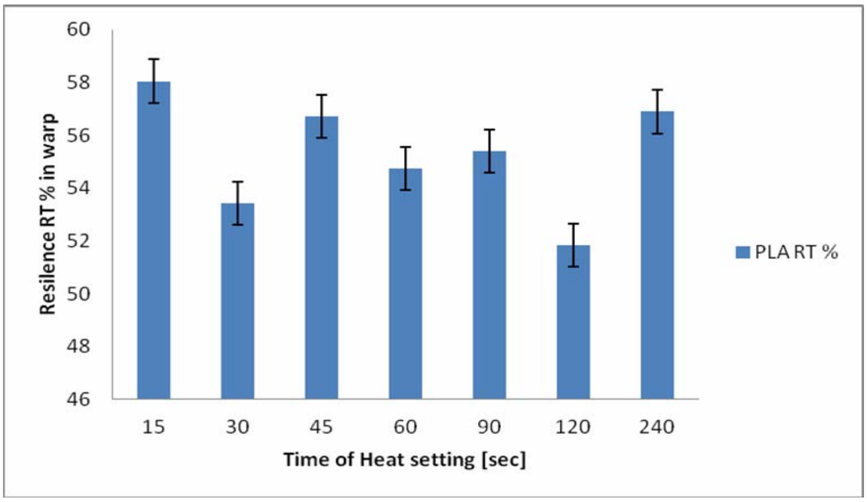

Figure 12. Effect of time of heatsetting on tensile resilience RT [%] in warp direction of knitted Ingeo Poly (lactic acid)

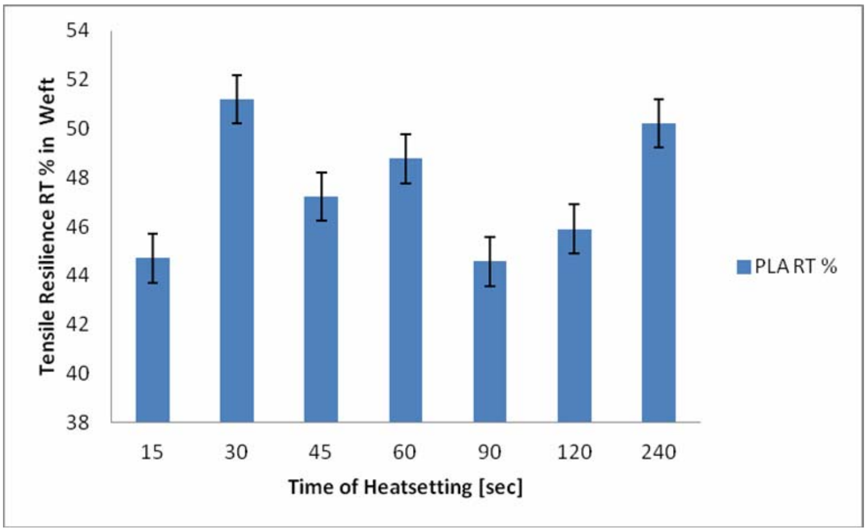

Figure 13. Effect of time of heatsetting on tensile resilience RT [%] in weft direction

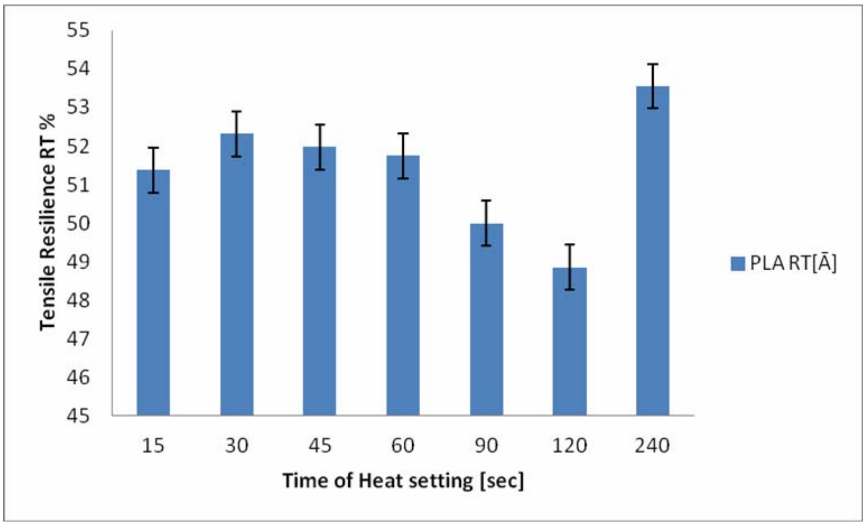

Figure 14. Mean effect of time of heatsetting on tensile resilience RT % on knitted Ingeo Poly (lactic acid) (PLA) fabric

4. Conclusion

The effect of time of heatsetting on tensile properties of knitted Ingeo™ Poly (lactic acid) (PLA) was determined using the KES-FB system of fabric testing. Tensile parameters determined included tensile extension [EM] %, linear extension, tensile energy [WT] gf.cm/cm^2 and tensile resilience [RT] %.

Increasing time of heatsetting had effect on tensile properties of PLA at varying times of 30s to 90s at temperature of 130°C. Optimum effect on tensile properties occurred at times of 30 – 45s. PLA exhibited a high tensile extension [EM] % between heatsetting time of 60s and 90s at 130°C. This implies a higher degree of softness. Very low extensibility could result in seam pucker and over feeding difficulty during making up resulting in garment discomfort. When a fabric is too extensible it may result to difficulties in laying/cutting, shape retention, pattern matching and fullness. Higher fabric extensibility enhances fabric hand [softness] and increased formability.

PLA showed a low linear extension implying a softer hand and a larger extension in the initial low load region of the load extension curve. This implies that PLA exhibited better formability as extensibility under small load represents in-place compressibility which is equivalent to formability.

At heatsetting temperature of 130°C. PLA exhibited a higher tensile energy WT gf/cm.cm^2 implying that PLA is extensible, flexible, soft and smooth.

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