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Biodegradable nonwoven bonded fabric from Tossa jute and polylactic acid fibre for carry bag

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A sustainable flexible nonwoven fabric has been developed using jute (*Corchorus olitorius*) and polylactic acid (PLA) fibres. The thermal bonding technique has been used to soften the PLA component which behaves as the matrix in jute fibre reinforcement. The central composite rotatable design has been adapted to understand the effects of the independent variables, such as PLA content, roller temperature and roller pressure on mechanical properties, such as tenacity, breaking elongation, initial modulus, energy-at-break, bursting strength and tear strength. Considering the linear, quadratic and two-way interactive effects of independent variables, the second-order polynomial has been suggested which proves good association. The optimised process parameters are PLA content 30%, jute content 70%, roller temperature 170°C and roller pressure 150 N/cm^2. The property comparison with commercial bag fabric shows that the developed jute-PLA fabric is better in many useful aspects. Three types of bags with carrying capacity of 2.5, 5 and 10 kg have been prepared. The results of the hanging test, wetting test, drop resistance test and atmospheric resistance test of the developed bag in comparison to the commercial bag show that the developed bag from jute-PLA performs better. No significant change is found after 10 wetting-drying cycles and hence, the bags are reusable. The fabric can be used successfully as a carry bag or shopping bag. As the process and components of developed fabric are ecofriendly, it will be sustainable and ecofriendly.

Keywords: Carry bag, Jute, Mechanical properties, Polylactic acid, Statistical design, Thermal bonding

1 Introduction

The advent of synthetic material has replaced the natural material in most of the uses during the last 50 years. Natural fibres have regained the field of attention for scientists and technologists due to their excellent properties[1,2]. The synthetic material has some inherent drawbacks, such as prone to damage in heat, electrostatic charge accumulator, low moisture content, non-biodegradable and non-friendly to the skin; along with its lot of advantages, such as durability, customer-friendly properties, water resistance, stain resistance, etc[3]. To overcome these drawbacks, the blending of natural and synthetic materials has been evolved. This combination reduces the disadvantages and increases the advantages of both items. Blended and composite materials of different kinds have been accepted for these use in apparel, transportation (automobile parts, aerospace, etc.), defence sector, building, construction industries, etc.[4,5].

Polylactic acid (PLA) is a non-toxic, thermoplastic, compostable polymer having a low *T*g of only 60-65°C and derived from corn. It is affordable, recyclable, inflamed burns with low smoke, resistant to moisture and grease[6]. PLA fibre possesses excellent resistance to sunlight; good tensile strength, elastic recovery and resilience; fair chemical resistance; and poor abrasion resistance and absorbency[7].

The information on jute based flexible bonded fabric is scanty. Most of the cases, rubber has been used[8,9] as the matrix. In some works, epoxy resin[10] or polyester resin has been used. In this work, PLA has been used in fibre form.

Conventional fabric preparation consists of about ten steps of sequential processing of fibres. Therefore, nonwoven which is a textile structure produced by the bonding or interlocking of an evenly spread fibrous sheet[11] has been made. It was found from theliterature[12] that thermal bonded nonwoven fabric can make a flexible composite with low areal density and sufficiently strong fabric. The work on thermal-bonded bast fibre nonwovens is found limited. A few researchers have studied[13] the contribution of fibre, binder, and web construction to the mechanical properties of nonwoven jute fabric.

Presently, carry bags are made of synthetic (sheet or spun bonded), which is polluting our environment on disposal. Jute fibre is well known for packaging due to

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its properties. But its use as carry bag is not popular due to its high areal density (about 250 g/m^2) and cost. In this study, an attempt has been made to develop a low areal density, flexible and sufficiently covered thermally bonded fabric from jute and PLA blend. The significant process variables on properties have been optimised using the statistical method. A biodegradable carry bag has been prepared and its performance is tested and finally compared to a similar type of synthetic bag. The main challenge of this work is to develop an environment-friendly carry bag keeping the thickness as low as possible to replace such widely used plastic carry bags. In this study, biodegradable PLA (30%) has been used to bond the thin (about 100 g/m^2) jute web using thermal calendaring system. The study describes a complete work considering development of fabric, optimisation of parameters, fabric quality and performance as a product. This will produce cheaper, sufficiently strong fabric for biodegradable carry bag. It will be totally biodegradable and hence ecofriendly to make a sustainable product.

2 Materials and Methods

2.1 Materials

Jute (*Corchorus olitorius*) of 'Tossa Daisee 3'gradewas used to prepare thermal-bonded nonwoven fabric, having the fibre properties, such as linear density 2.58 tex, tenacity 24.30 cN/tex, and extension-at–break 1.50%. Commercially available poly-lactic acid fibre was used as adhesive on melting. The quality of low melt grade, 76 mm, 7 den PLA fibre, procured from Miltex Ecofibre Pvt Ltd, Tamilnadu, India, were as follows: density 1.25 g/cc, tenacity 6 g/den, elongation-at-break 7%, moisture regain 0.5%, glass transition temperature 60–65 °C, and melting temperature 130-140 °C.

2.2 Methods

The significant independent process variables of jute-PLA thermal-bonded nonwoven are PLA content, roller temperature and roller pressure. Their limits have been decided from the experience of preliminary trials, literatures and experience. PLA content has been kept as low as possible to achieve sufficient properties for shopping bag fabric. Roller temperature and pressure have been selected as per preliminary trails as it is new type of fabric. The limits, actual and coded values of different factors are given in Table 1.

2.2.1 Developing Design Matrix

The central composite rotatable design has been used to understand the effects of the variables on properties. It contains twenty samples with 8 full factorial designs, 6 centre points and 6 star-points[14, 15].To correlate the effects of factors and the response, the following second-order standard polynomial was considered[16]:

Table 1 — Actual and coded values of independent factors

Factors	Code				
	-1.682	-1	0	+1	+1.682
PLA content (x_1), %	8	12.5	19	25.5	30
Roller temperature (x_2), °C	120	132.2	150	167.8	180
Roller pressure × 10 (x_3), N/cm^2	8	10.8	15	19.2	22

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3$$

where y represents the response of the dependant variable; and b_0, b_1, b_2, ……....b_{11},…......b_{23} are the coefficients of the model; and x_1, x_2 and x_3 are independent variables as shown in Table 1.

2.2.2 NonwovenFabric Preparation

Jute is brittle, hard and meshy fibre bunch. In jute processing, batching oil-water emulsion is required to make the fibre soft and pliable. In this study, instead of batching oil, suitable vegetable oil in low quantity is used for this purpose to keep the product ecofriendly. In jute spinning, it is recommended to use higher amount of oil. But in this case, as thermal bonded nonwoven will be made, the oil content has kept 1%. Therefore, an emulsion of 1% castor oil-in-water[17] was sprayed on jute reed for softening and then kept for 8 h in a closed bin. Then it was processed in a breaker card and finisher card of the jute processing system. The sliver from the finisher card was hand opened. The PLA fibre was opened in the card of the Dilo nonwoven line. The opened PLA and jute were mixed thoroughly according to the preset proportion by stack mixing procedure and fed to Dilo nonwoven plant, comprising a card, a cross-lapper and needle loom. The pre-needled fabric has been prepared with the following parameters:

Stroke	:	200 per min
Needle loom feed	:	0.90 m/min
Needle loom delivery	:	1.01 m/min
Needles	:	40 per cm of width
Stitch density	:	90 per cm
Advance/stroke	:	4.5 mm
Feed lattice speed	:	0.40 m/min
Doffer speed	:	19.90 m/min
Cross lapper speed	:	20.20 m/min
Feed in card	:	600 g/m^2

The needled web was produced and then fed to the conveyer of the thermal bonding machine, comprising a pair of hot rollers followed by a pair of cold rollers (Fig. 1). The hot roller temperature and pressure were varied according to the design proposed using the central composite rotatable design as shown in Tables 1 and 2. The surface speed of hot rollers, number of passages and nominal areal density of fabric were 1.5 m/min, 2 and 120 g/m^2 respectively.

2.2.3 Measurement of Fabric Properties

The tensile properties of the nonwoven fabrics, in the machine direction, were determined at 65% RH and 22-25^o C on an Instron Tensile Testing machine(model number 5567) according to ISO 9073-18:2007 standard. The test conditions were: test length 10 cm, cross-head speed 5 cm/min, and strip width 2.5 cm. The fabric tenacity and elongation-at-break were determined (ISO 9073-18:2007) as follows :

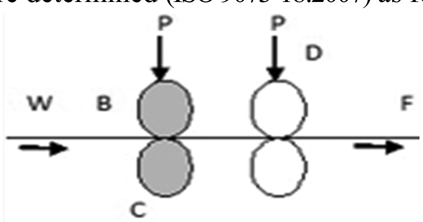

Fig. 1 — Schematic diagram of thermal bonding machine (W – fibre web, P – pneumatic pressure, B – hot roller with dot surface, C – hot roller with smooth surface, D – cold roller with smooth surface, and F- bonded fabric)

Tenacity (cN/tex) =Breaking load (cN)/ [Specimen width (mm) × Fabric area density (g/m^2)]

Breaking elongation,% = Elongation-at-break (cm) × 100 / Gauge length (cm)

Initial modulus was expressed as the modulus (stress/strain) at 1% elongation. Energy-at-break was expressed as the area under the load-elongation curve till the breaking point. An average of twenty tests for each sample has been reported.

Areal density, bursting strength, seam strength and tear strength have been tested following ASTM D3776, IS 1966, ASTM D1683 and ASTM D2261 respectively. The bending load was measured according to the method reported earlier[18].

2.2.4 Preparation of Carry Bag

Three types of carry bags namely (i) low capacity, (ii) medium capacity and (iii) high capacity were prepared (Fig. 2). All bags were of the same size(30 cm

Fig. 2 — Carry bags from jute-PLA fabric (a) low capacity, (b) medium capacity, (c) high capacity and (d) commercial bag

Table 2 — Properties of mesta adhesive bonded nonwoven fabrics

Exp. No.	Independent variables			Properties					
	PLA content, %	Roller temperature ^{0}C	Roller pressure×10 N/cm^2	Tenacity cN/tex	Breaking elongation %	Initial modulus cN/tex	Energy-at-break mJ	Bursting strength × 10 N/cm^2	Tear strength× 10 N
1	25.5	167.8	19.2	2.02	3.88	44.6	162.7	6.9	5.12
2	12.5	167.8	19.2	1.57	11.71	27.9	451.2	5.1	4.69
3	25.5	132.2	19.2	1.8	48.52	17.7	1075.3	6.2	5.67
4	12.5	132.2	19.2	1.43	21.26	13.8	773.5	5.8	4.26
5	25.5	167.8	10.8	1.89	5.99	72.8	143.6	5.5	5.38
6	12.5	167.8	10.8	1.28	16.45	15.3	194.2	4.7	4.39
7	25.5	132.2	10.8	1.79	34.95	49.4	329.1	5.9	5.46
8	12.5	132.2	10.8	1.48	39.32	57.2	470.4	4.3	4.14
9	30	150	15	2.06	12.03	21.7	238	6.8	5.81
10	8	150	15	1.57	9.39	18.2	484.9	4.3	4.15
11	19	180	15	1.68	29.42	14.3	173.2	5.2	4.72
12	19	120	15	1.46	15.31	9.7	1749.3	5.4	4.63
13	19	150	22	1.97	19.65	20.2	638.4	4.8	4.47
14	19	150	8	1.62	7.75	12.7	334.1	4.3	4.09
15	19	150	15	1.88	7.69	18.2	138.4	5.3	4.83
16	19	150	15	1.92	8.09	15.6	124.8	5.7	4.86
17	19	150	15	1.85	7.85	17.4	136.6	5.5	4.91
18	19	150	15	1.88	7.16	18.9	103.8	5.4	4.86
19	19	150	15	1.93	8.72	15.3	154	5.8	4.83
20	19	150	15	1.82	7.66	16.7	124.9	5.3	4.82

× 28 cm× 3.5 cm) and tested for the maximum carrying capacity (measured with sand) of (a) 2.5 kg, (b) 5 kg and (c) 10 kg depending on design, sewing and use of cotton tape. The weight of the bag was 41, 45, 58 g respectively. Two types of commercial bags made from spun-bonded nonwoven and plastic sheets were collected for comparison. All the comparison was made with medium capacity developed bags, because it is performance wise closer to the commercial bag.

2.2.5 Performance of Developed Bag

Hanging test following QB/T 2058(bags containing 2 kg/4 kg of sand were hung after sewing the open face and vertical deformation was measured after 7 and 15 days); wetting test following ASTM D 559-03(repeated complete wetting in water with 1% non-ionic surfactant and subsequent sun drying for 5 /10 times); drop test (a successive drop of 1 kg sand-filled bag from 500 mm height was done till rupture or 4 falls) following IS 13035; and atmospheric exposure test(strength loss and colour change of bag after keeping in an open place where sunlight, rain and dew may come without hindrance in June for 15 and 30 days).

3 Results and Discussion

As per the central composite rotatable design[13, 14], the values of three independent variables (PLA content, roller pressure and roller temperature) and properties, namely tenacity, breaking elongation, initial modulus, energy-at-break, bursting strength and tear strength, of twenty samples have been evaluated (Table 2). After the computation using Statistica 7 software, the regression coefficients of the proposed second-order polynomial are shown in Table 3. With these coefficient values, the mathematical model can be expressed for each response. For example,

$$\text{Initial modulus} = 721.7991-14.6636x_1+0.1279x_2-5.5119x_3+0.0085x_1^2-21.3210x_2^2+0.2519x_3^2+0.0844x_1x_2-0.1332x_1x_3+0.0995x_2x_3$$

where x_1 is the PLA content; x_2, the roller pressure; and x_3, the roller temperature.

Similar models can be derived from Table 3 for other dependent variables.

To study the effect of variables on the responses, the contour diagrams have been plotted (Figs 3-7) from the data of Table 2. ANOVA results of the developed model are shown in Table 4. The correlation coefficient of the model and validation by the predicted and observed values of fabric with other process parameters are shown in Table 5. A very good correlation has been observed.

The coefficient of variation of five web areal densities (80, 100, 120, 140, and 160 g/m^2) from jute have been calculated. Fifty (50) readings of randomly taken (10 × 10 cm) web weight have been used for each areal density to calculate CV%. It has been found that CV% decreases significantly from 80 g/m^2 to 120 g/m^2 and after that, there is no decrease. Hence, the final fabric has been made from 120 g/m^2 web. Figure 8 shows the effect of areal density on CV%.

3.1 Effect on Tenacity

Figure 3(a) shows that as PLA content increases for a fixed roller temperature and roller pressure (150 N/cm^2), tenacity also increases above 120 ºC of roller temperature. In this condition, the bonding between jute and PLA improves due to the melting of PLA fibre. With the increase of PLA proportion, the fabric becomes stronger due to the presence of more number of stronger and finer PLA fibre, which facilitates the better bonding.

When roller temperature increases for a set PLA %, tenacity initially increases upto 150 ºC, and then decreases. The same effect is observed with an increase in temperature [Fig. 3(b)]. The initial increase of tenacity is due to better bonding, but at high temperature, the melted PLA becomes brittle and

Table 3 — Regression coefficients of model

Coefficients	Tenacity cN/tex	Breaking elongation, %	Initial modulus cN/tex	Energy-at-break, mJ	Bursting strength× 10 N/cm^2	Tear strength× 10, N
b_0	-6.04	490.98	721.80	17851.16	3.65	-4.37
b_1	0.01	2.29	-14.66	21.28	-0.08	0.23
b_2	-0.00	0.06	0.13	1.02	0.00	0.00
b_3	0.10	-5.60	-5.51	-229.18	-0.04	0.04
b_{11}	-0.00	0.03	0.01	0.80	0.00	-0.00
b_{22}	-0.02	-8.31	-21.32	57.92	0.51	0.38
b_{33}	-0.00	0.21	0.25	5.01	-0.01	-0.01
b_{12}	0.00	-0.05	0.08	-0.54	0.00	-0.00
b_{13}	-0.00	0.16	-0.13	0.94	-0.00	-0.00
b_{23}	0.00	-0.00	0.10	-1.29	0.00	-0.00

forms weak bonding. Figure 3 (b) shows that tenacity increases for a sample with PLA 19%, with the increase of roller pressure upto 220 N/cm^2.This is due to better melting and bonding in higher pressure.

The maximum tenacity (2 cN/tex) has been achieved with 30% PLA, 170ºC temperature and 150 N/cm^2 pressure. The minimum tenacity (0.8 cN/tex) has been achieved with 6% PLA, 110ºC temperature and 150 N/cm^2 pressure.

3.2 Effect on Extension-at-break

Figure 4(a) shows that as PLA content increases with roller pressure 150 N/cm^2, extension-at-break decreases

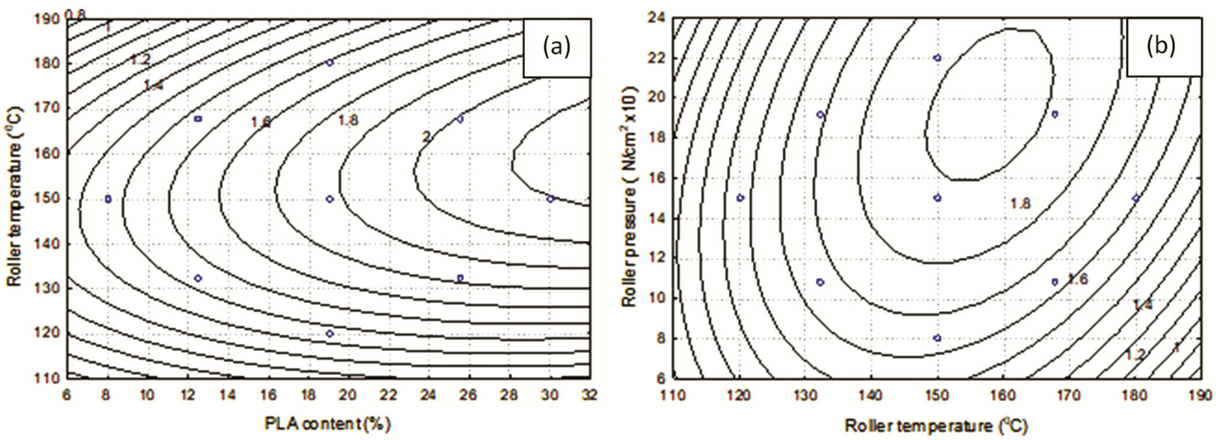

Fig. 3 — Tenacity of jute-PLA fabric, (a) effect of PLA% and temperature for 150 N/cm^2 pressure, and (b) effect of temperature and pressure for 19% PLA content

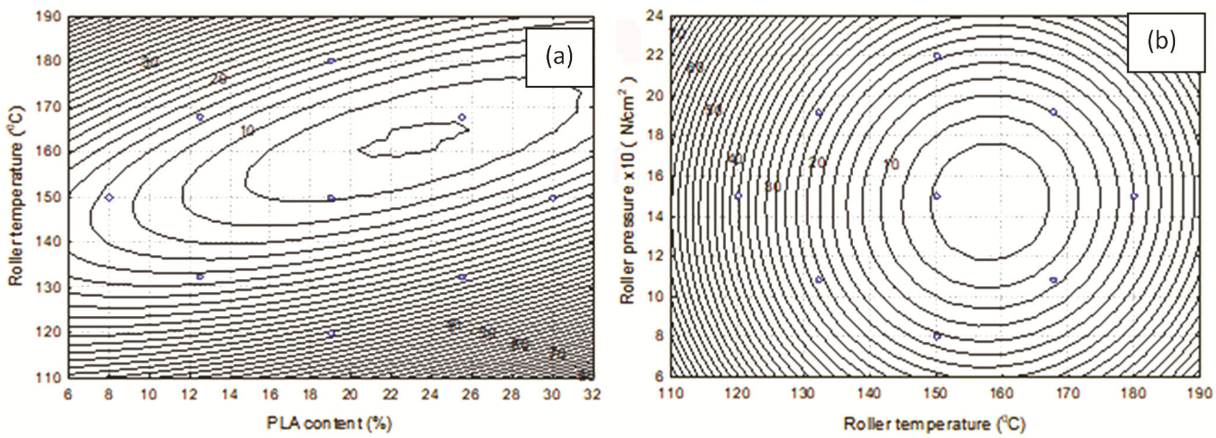

Fig. 4 — Extension-at-break of jute-PLA fabric (a) effect of PLA% and temperature for 150 N/cm^2; and (b) effect of temperature and pressure for 19% PLA content

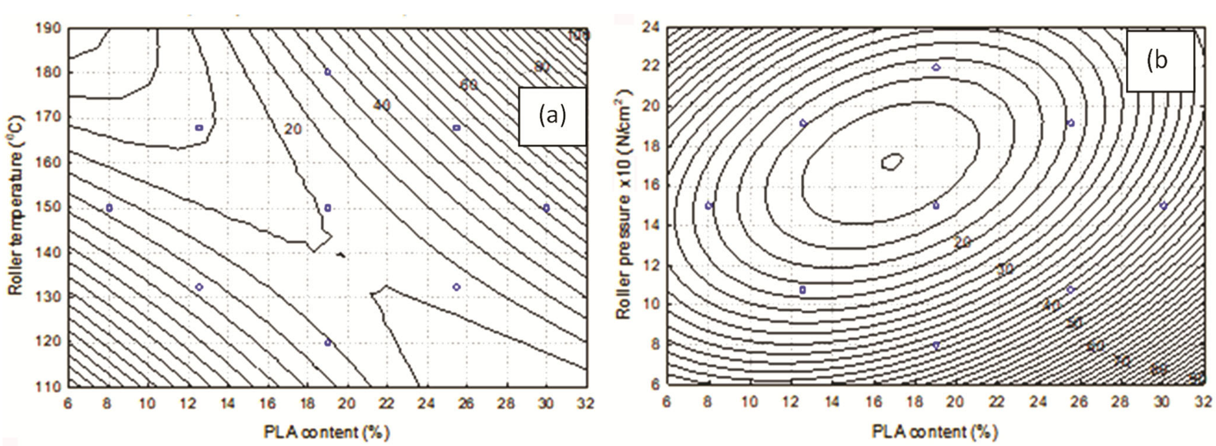

Fig. 5 — Initial modulus of jute-PLA fabric (a) effect of PLA% and temperature for 150 N/cm^2; and (b) effect of PLA% and pressure for 19% PLA content

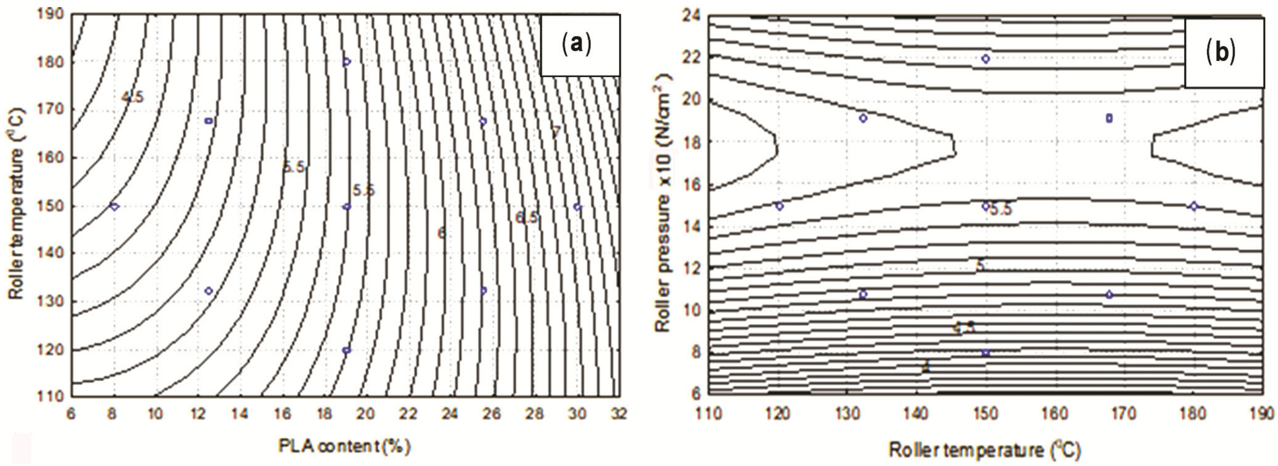

Fig. 6 — Bursting strength of jute-PLA fabric (a) effect of PLA% and temperature for 150 N/cm^2; and (b) effect of temperature and pressure for 19% PLA content

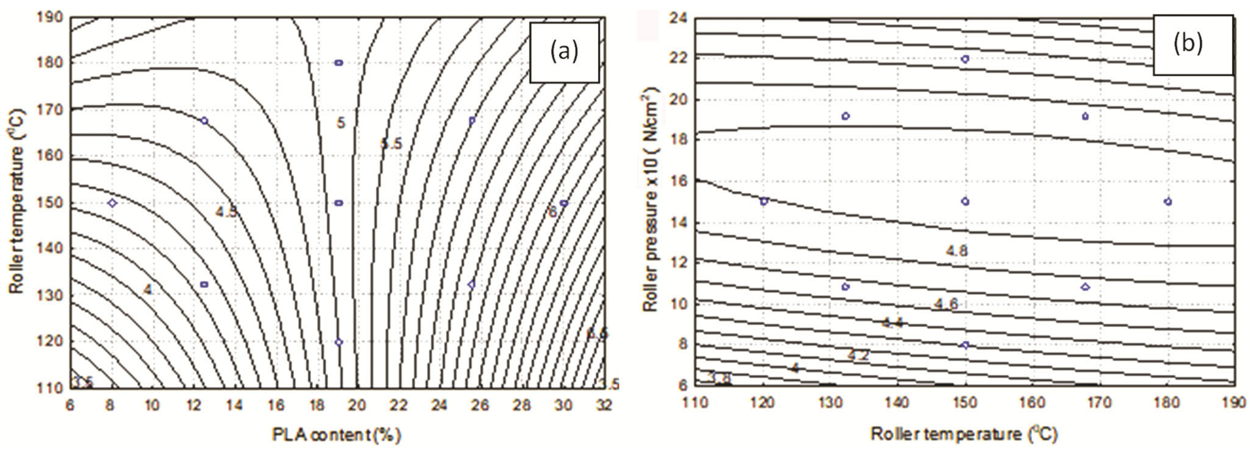

Fig. 7 — Tear strength of jute-PLA fabric (a) effect of PLA% and temperature for 150 N/cm^2; and (b) effect of temperature and pressure for 19% PLA content

Table 4 — ANOVA of proposed model

Parameters	Mean/sum square	1st order term	2nd order term	Lack of fit	Pure error	F-ratio	R^2
d.f.	-	3	6	5	5	-	-
Tenacity, cN/tex	SS	0.305543	0.305543	0.049627	0.0136	3.65	0.94
	MS	0.305543	0.305543	0.007736	0.00212		
Breaking elongation, %	SS	505.66	1234.566	173.029	3.351	51.63	0.55
	MS	505.66	1234.566	13.957	0.2703		
Initial modulus, cN/tex	SS	941.247	2121.055	286	25.148	11.37	0.87
	MS	941.247	2121.055	23.083	2.0297		
Energy-at-break, mJ	SS	1658644	1187922	106864	1429	74.78	0.53
	MS	1658644	1187922	21387	286		
Bursting strength× 10, N/cm^2	SS	7.13884	1.07113	1.40297	0.28	5.01	0.82
	MS	7.13884	1.07113	0.260552	0.052		
Tear strength× 10, N	SS	3.605176	0.706389	0.109098	0.019483	5.59	0.94
	MS	3.605176	0.706389	0.01734	0.003097		

d.f.– Degree of freedom, SS – sum square and MS – mean square.

Table 5 — Correlation between predicted and observed values

Property	Predicted value (x_1)	Observed value (x_2)	Correlation %
Tenacity, cN/tex	1.78	1.80	98.67
Breaking elongation, %	18.59	19.65	94.60
Initial modulus, cN/tex	19.05	20.20	94.31
Energy-to-break, mJ	136.33	124.80	91.54
Bursting strength ×10, N/cm^2	6.27	6.20	98.92
Tear strength × 10, N	5.98	5.81	97.11

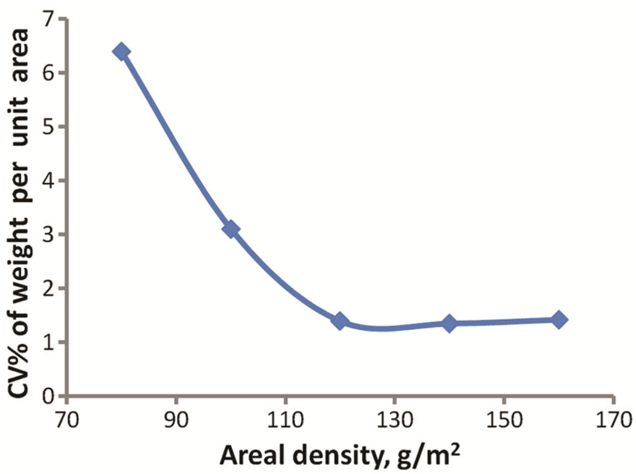

Fig. 8 — Irregularity of thermo-bonded fabric

initially up to 24% PLA, followed by an increase. It occurs between 130 ºC and 170 ºC of roller temperature. Below 130ºC, extension increases with the increase in PLA content, whereas above 170ºC it decreases. Within 130 - 170 ºC, the initial decrease in extensibility is due to better boding and reduction of fibre slippage, but above 24% PLA, the increase in extensibility is due to the better contribution of higher extensible PLA fibre. Below this range of temperature, the increase in extensibility is mainly because of insufficient bonding with higher PLA content. Above this range, it implies better bonding by the decrease in extensibility. From 130 ºC, fibres start taking load due to better bonding and hence extension increases. Above 170 ºC, the decrease in extensibility is due to the brittle nature of bonding due to excessive heat.

The same figure also demonstrates the effect of roller temperature on extension-at-break for roller pressure 150 N/cm^2. Extension-at-break decreases with an increase in roller temperature initially, but after 130 - 170 ºC, it increases. This change over temperature range increases with increase of PLA %. From 130 ºC, fibre bonding improves and hence extension increases. Above 170 ºC, the decrease in extensibility is due to the brittle nature of bonding due to excessive heat.

Figure 4(b) shows that when roller temperature increases with PLA content 19%, extension-at-break reduces till 170 ºC due to better bonding, beyond which it increases due to the brittle nature of bonding in higher temperature. As roller pressure increases extension-at-break decreases initially, but after 160N/cm^2, it increases. The initial decrease in extension is because of better bonding. Above 160N/cm^2, the bonds become weak due to high pressure.

The maximum extension-at-break (80%) has been achieved with 32% PLA, 110ºC temperature and 150 N/cm^2 pressure. The minimum extension-at-break (10%) has been achieved with 22% PLA, 160ºC temperature and 150 N/cm^2 pressure.

3.3 Effect on Initial Modulus

Figure 5(a) shows that with the increase in PLA or roller temperature for constant roller pressure of 150 N/cm^2, the initial modulus initially decreases and then increases after a minimum value. This changeover point is around 170 ºC for 6% PLA, which slowly reduces to 120 ºC for 26% PLA content. With the roller temperature, a similar trend follows. As PLA increases, the inter-fibre friction in blend decreases, resulting in lowering of initial modulus in lower temperature. An increase in the initial modulus in the latter part is due to better bonding. But with the increase of temperature, bonding improves in lower PLA%, which helps in shifting of changeover point.

According to Fig. 5(b), the initial modulus initially decreases and then increases with the increase of roller temperature and pressure when PLA content is 19%.This changeover point slowly reduces from 190ºC to 110 ºC withan increase of roller pressure from 6 N/cm^{2}to 24 N/cm^2. The explanation of this phenomenon is the same as observed earlier for Fig. 5(a).

The maximum initial modulus (100 cN/tex) has been achieved with 30% PLA, 180ºC temperature and 150 N/cm^2 pressure. The minimum initial modulus (20 cN/tex) has been achieved with 20% PLA, 150ºC temperature and 150 N/cm^2 pressure.

3.4 Effect on Bursting Strength

Figure 6(a) describes that as PLA % increases with roller pressure 150 N/cm^2, bursting strength increases in all levels of roller temperature. This increase is mainly due to better and more bonding. This figure also shows that with the increase of roller temperature, bursting strength decreases up to 18% PLA content and subsequently remains constant.

At lower PLA %, the bonding is inadequate. Above 18%, bonding improves slowly with higher temperature and hence bursting strength improves.

Figure 6 (b) shows that there is an insignificant change of bursting strength with an increase of roller temperature. As roller pressure increases, the bursting strength initially increases but beyond 180 N/cm^2, it reduces. Roller pressure up to 180 N/cm^2 facilitates better melting of PLA and bonding. Further, higher pressure reduces bursting strength due to brittle and weak bonding.

The maximum bursting strength i.e. 75 N/cm^2 has been achieved with 30% PLA, 170ºC temperature and 150 N/cm^2 pressure. The minimum bursting strength i.e. 40 N/cm^2 has been achieved with 19% PLA, 150ºC temperature and 70 N/cm^2 pressure.

3.5 Effect on Tearing Strength

Tear strength increases with an increase of PLA%, as shown in Fig. 7(a), for constant roller pressure (150 N/cm^2). The increase in tear strength is mainly due to the increase of strong PLA fibre and higher bonding. This figure also shows that with an increase in temperature, tear strength increases for below 18% and above 22% PLA content. Between 18% and 22 % PLA content, there is almost no change. As temperature increases, tear strength also increases due to higher melting and better bonding.

Figure7(b) shows that as roller temperature increases with 19% PLA content, there is almost no change in tear strength. In Fig. 5(a), it is observed that within 18-22% PLA, an increase in temperature does not affect tear strength, because at lower temperature the fabric reaches its optimum tear strength due to better bonding. When pressure increases tear strength increases, up to 170 N/cm^2. This increase is due to improvement in bonding with higher pressure.

The maximum tearing strength (6.5 N) has been achieved with 30% PLA, 130ºC temperature and 150 N/cm^2 pressure. The minimum tearing strength (3.5 N) has been achieved with 6% PLA, 110ºC temperature and 150 N/cm^2 pressure.

3.6 Optimisation

Considering the maximum and minimum values of all the functional properties and their relation with process parameters, the optimised jute-PLA bonded fabric of 120 g/m^2 has been prepared from 30% PLA, 170°C roller temperature and 150 N/cm^2 roller pressure, keeping other parameters the same. This fabric bending load has been measured as 30.2 cN in the loop method. It is observed that the effects of PLA% and temperature are predominant on tenacity (72% & 27%), initial modulus (27% & 28%) and bursting strength (74% & 37%) respectively. The correlation of tear strength is significant with PLA % (87%) and energy-at-break is significant with roller pressure (66%) and temperature (27%), where as breaking elongation is significant with pressure (41%).Data shown within bracket is the correlation coefficient.

3.7 Confirmation of Model

The model equations developed have been tested with a newly prepared jute PLA bonded nonwoven sample. A fabric with 25% adhesive concentration, 150 N/cm^{2}roller pressure and 150^{0}C roller temperature in the same machine and process has been prepared. It is found that the tested and predicted values of all the mechanical properties (Table 5) show a good agreement. This confirms that the proposed models are acceptable. Hence, knowing PLA %, pressure and temperature, the functional properties of the nonwoven can be predicted satisfactorily with the help of these regression equations.

The analysis of variance (ANOVA) technique has been used to check the adequacy of the developed models. For this purpose, the F-ratio is defined as the division between Lack of fit (mean square) and Error (mean square). Accordingly, the F-ratios of the developed models are calculated and compared with the corresponding tabulated values for a 95% level of confidence. Table 4 shows the ANOVA of the developed models. As the calculated values of F-ratio for tenacity, bursting strength and tear strength are around 5 and models are considered adequate. Though the initial modulus shows a higher F-ratio, it is observed that their correlation coefficient are very high (87%), the models are acceptable. This also corroborates the correlation shown in Table 5. Breaking elongation and energy-to-break show high F-ratio as well as comparatively low correlation coefficient, defining that these models cannot reject the null hypothesis in the 95% confidence level though they can depict an idea about their values. As many other factors are influencing these two parameters with high variability, the fitting with the model has not been established.

3.8 Relationship and Clustering Among Variables

It is observed from the tree diagram of cluster analysis (Fig. 9) that the independent variables,

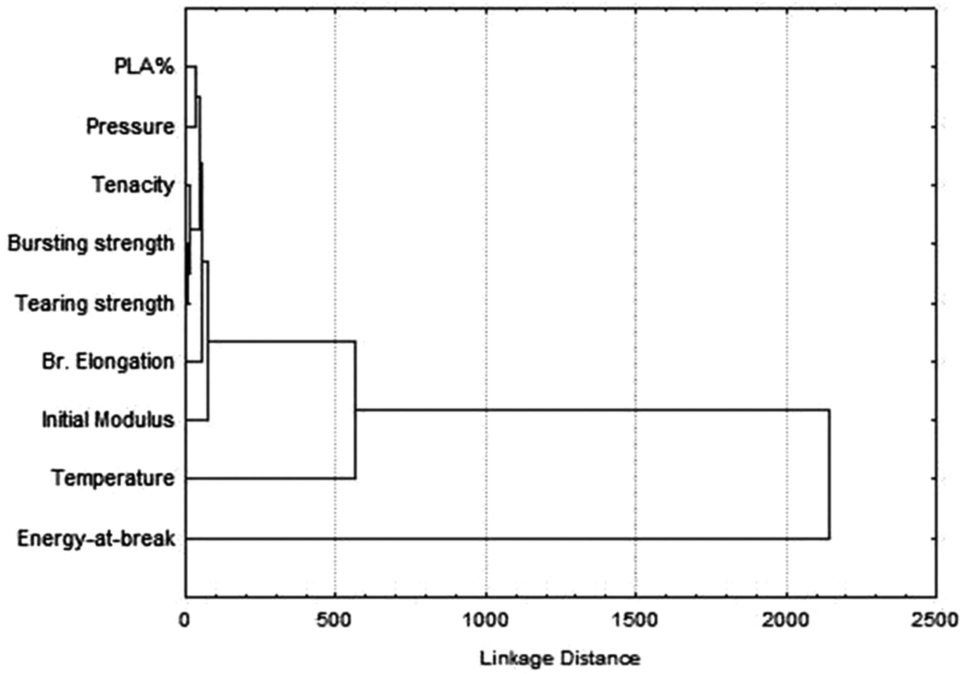

Fig. 9 — Tree diagram with Euclidean distance of variables using cluster analysis

PLA% and roller pressure form a small cluster and temperature, are completely different entities. Out of dependant variables tenacity, bursting strength and tearing strength fall under a separate cluster and are influenced by PLA% and roller pressure. From this study, it can be explained that the small clusters are much influenced by an individual variable, namely temperature as it shows the higher value of Euclidean distance. Breaking elongation, initial modulus, and energy-at-break are separate entities. Breaking elongation and initial modulus depend on different sub-clusters including PLA% and roller pressure. The Euclidean distance of temperature and energy-at-break are 560 and 2150 respectively. These can also be supported by the correlation coefficients between different variables.

3.9 Comparison between Developed Fabric and Fabric from Synthetic Commercial Bag

The properties of the developed bag have been compared with commercial carry bags from spun bonded nonwoven (82 g/m^2) (Table 6). The comparison shows that the developed jute-PLA fabric has higher areal density, initial modulus, bursting strength, seam strength, tear strength and stiffness, whereas lower breaking extension and creep. The tenacity is comparable to the spun-bonded fabric. The high linear density of the developed fabric is due to coarse jute fibre. The reduction of linear density of developed fabric increases irregularity. Low elongation, high initial modulus and low creep of developed fabric improve dimensional stability, which is very important for a carry bag. Higher seam strength and tear strength are useful for a carry bag. High bending load is due to rigid jute fibre.

3.10 Performance of Bag from Developed Fabric

The performance of the developed fabric has been tested in the bag form (type b) and compared with a commercial bag (spun-bonded). Table 7 shows the results of the hanging test, repeated wetting test, drop resistance and atmospheric resistance. The hanging test reveals that the commercial bag shows 0.9% vertical deformation after 7days of hanging with 2 kg of sand whereas the developed bag has no deformation even after 14 days. The deformation values of the commercial and developed bag after 14 days with 4 kg sand are 2.9% and 0.3% respectively. Low elongation, high initial modulus and low creep of developed fabric are responsible for lower vertical deformation. Five times wetting-drying cycle shows no weight loss or dimensional change in both types of bag. After the increase of cycles to 10, there is no change observed in dimension but 0.2% weight loss is observed in developed bag. Therefore, the fabric is reusable. This weight loss is due to the removal of adhered external material and loose/ broken fibre particles. Drop test reveals that

Table 6 — Comparison between developed fabric and fabric from the synthetic commercial bag
[Bulk density 0.203 g/cc and void percentage of developed fabric 85]

Sample	Areal density g/m^2	Tenacity cN/tex	Breaking elongation %	Initial modulus N/mm^2	Creep with 4 kg load %	Bursting strength kg/cm^2	Seam strength kg	Tear strength kg	Bending load g
Spun bonded fabric	82	1.83	62.89	6.93	11	6.7	2.08	1.79	36
Jute-PLA fabric	118	1.86	3.03	154	3.6	9.2	2.11	2.45	72

Table 7 — Performance test of bags

Bag type	Hanging test Vertical deformation, %				Wetting test Wetting-drying cycle				Drop resistance				Atmospheric resistance			
	2 kg sand		4 kg sand		5 times		10 times						Strength loss, %		Colour change	
	After 7 days	After 14 days	After 7 days	After 14 days	DC %	WL %	DC %	WL %	1 drop	2 drop	3 drop	4 drop	After 15 days	After 30 days	After 15 days	After 30 days
Jute-PLA bag	0	0	0	0.3	0	0	0	0.2	Pass	Pass	Pass	Pass	1.3	1.7	Yes	Yes
Commercial bag	0.9	1.2	2.1	2.9	0	0	0	0	Pass	Burst	-	-	5.6	7.3	No	Yes

DC – Dimensional change, WL – Weight loss.

commercial bag bursts in the second drop mainly from the folds or seals. The developed bag has been tested for up to four drops and no damage is found. This is due to the high bursting strength, seam strength and tear strength of the fabric. The atmospheric test shows that developed bags can sustain atmospheric hazards better than commercial bags. Exposure of developed bag for 15 and 30 days shows strength loss of 1.3% and 1.7% respectively, whereas commercial bag shows strength loss of 5.6%. The de-colouration effect on the same atmospheric exposure is faster in the developed bag. These testing has been done at Kolkata, India, under following weather condition in June 2018: average day time (high) temperature 34^{0}C and night (low) temperature 26.5^{0}C; average rainfall 288 mm; and average humidity 77%. There has been no dew during that period.

4 Conclusion

The mechanical properties of a sustainable and biodegradable flexible composite using jute and polylactic acid fibres have been developed using the thermo-bonding technique. The optimised process parameters are PLA content 30%, jute content 70%, roller temperature 170ºC and roller pressure 150 N/cm^2. The lowest possible areal density is120 g/m^2, below which the irregularity increases. A second-order polynomial has been developed for different mechanical parameters individually i.e. tenacity, breaking elongation, initial modulus, bursting strength and tear strength. The correlation coefficient of the model and validation by the predicted and observed values from independent variables illustrates a very good association. The cluster analysis show that PLA% and roller pressure form a small cluster and temperature is a completely different entity. Out of dependent variables tenacity, bursting strength and tearing strength fall under a separate cluster and are influenced by PLA% and roller pressure.

The comparison with commercial bag fabric shows that the developed jute-PLA fabric is of higher areal density, initial modulus, bursting strength, seam strength, tear strength and stiffness; whereas, lower breaking extension and creep. Though the bending load is slightly higher than a commercial bag, there is no difficulty in using it as carry-bag fabric. The tenacity is comparable to the spun-bonded fabric. Three types of bags with carrying capacities of 2.5, 5 and 10 kg have been prepared. The hanging test, drop resistance and atmospheric resistance show that the developed bag performs better than the commercial bag, whereas the performance of the repeated wetting-drying test is comparable in the case of both bags. As there are no significant changes observed up to 10 repeated wetting-drying cycles, the fabric can be reused successfully. Therefore, the developed fabric can be used successfully as a carry bag or shopping bag. As the process (mechanical and electrical) and components (jute and PLA) of developed fabric are eco-friendly, it will be a sustainable and ecofriendly.

References

1 Banerjee P K, Environmental textiles from jute and coir, in *Handbook of Natural Fibres*, Vol 1, edited by R M Kozlowski (Woodhead Publication Ltd, UK.), 2012.

2 Rowell R M, Natural fibres: Types and Properties,in *Properties and Performance of Natural fibre composites*,

Edited by K L Picering (Wood head Publishing Ltd., England), 2008, Chap 1,3-66.

3 Morton W E &Hearle J W S, *Physical Properties of Textile Fibres* (Woodhead Publication Ltd, UK.)2008.

4 Oxtoby E, *Spun Yarn Technology* (Butterworth-Heinemann, UK), 2013, 19-24.

5 Kelly A& Mortensen A, Composite Materials: Overview, in *Encyclopedia of Materials: Science and Technology*, edited by K H J Buschowetal (Elsevior Ltd, UK.),2001.

6 Ross G, Ross S & Tighe B J, Bioplastics: New Routes, New Products, in *Brydson's Plastics Materials*, 8thedn, edited by Marianne Gilbert (Butterworth-Heinemann, UK) 2017, Chap 23,631-652.

7 Farrington D W, Lunt J, Devies S& Blackburn R S, Poly(lactic acid) fibers, in *Biodegradable and Sustainable Fibres*, edited by Richard Blackburn (Woodhead Publishing Ltd, England.), 2005,Chap 6.

8 Mahesh V, Joladarashi S & Kulkarni SM, *Materials Res Express*, 6(5) (2019) 5503.DOI: 10.1088/2053-1591/ab0164.

9 Mahesh V, Joladarashi S & Kulkarni S M, *Composite Structures*, 225 (2019). http://doi.org/10.1016/j.compstruct. 2019.111190.

10 Mahesh Vinyas, Mahesh Vishwas & Harursampath D K, *Adv Materials Processing Technol*, 8(2)(2021) 380. DOI: 10.1080/2374068X.2021.1934643

11 Chapman R A, Chemical bonding, in *Handbook of Nonwovens,* edited by S J Russell (Woodhead Publishing Limited, UK), 2007,330-367.

12 Lin J H, Xu Z H, Lei C H & Lou C W, *Text Res J*, 73(10)(2003)917.

13 Pourmahammadi A, Thermal bonding, in *Handbook of Nonwovens*, edited by S J Russell (Woodhead Publishing Limited, England),2007.

14 Montgomery D C, *Design and Analysis of Experiments* (John Wiley & Sons, New York)2005.

15 Sengupta S & Debnath S, *Ind Crops Prod*, 116(2018) 109.

16 Devies O L, *The design and analysis of industrial experiments* (Longman Group Limited, New York), 1978.

17 Basu G, De S S, Samanta A K, *Ind Crops Prod*, 29 (2009) 281.

18 Sengupta S, Debnath S & Sengupta A, *J Measurement*, 87 (2016) 205.