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Preparation of value added composite boards using finished leather waste and plant fibers—a waste utilization effort in Ethiopia

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Abstract Preparation of composite materials with better mechanical properties and agreeable use is a need of the time for the reason that it is eco-friendly. Having this objective in mind, the work of preparing value-added leather composites using finished leather waste and various plant fibers as raw materials is done in the laboratory of Council of Scientific and Industrial Research–Central Leather Research Institute, India. In the leather goods and footwear manufacturing industries, about 20–30% of leather is discarded as waste, and presently it is imperative to make effort to utilize this waste in Ethiopia because it is huge and untapped resource. The recycled leather (RCL) as control and its composite boards (CBs) which are the mixtures of leather fibers with plant fibers like jute (*Corchorus trilocularis* L.), hibiscus (*Hibiscus cannabinus*), sisal (*Agave sisalana*), palm (*Phoenix dactylifera*) and enset (*Ensete ventricosum*) in the proportion of 10, 20, 30, and 40% are characterized for their physicochemical properties (tensile strength, elongation at break, stitch tear strength, water absorption, water desorption, and flexing strength), scanning electron microscope (SEM), Fourier transform infrared, thermogravimetric analysis (TGA), and differential scanning calorimeter (DSC). Composites exhibited better mechanical properties compared to those of control boards. SEM pictures showed the composite nature of the boards. TGA studies revealed better thermal stability for composites. In the DSC study, the CBs of RCL-S and RCL-P exhibited higher melting point values than those of RCL-J, RCL-H, and RCL-E samples. Based on these results, all the composite boards may be used as raw material for the preparation of consumer products such as insoles, chapel-uppers, wallets, light hand bags, mouse pads, roofing, wall partitioning, and components of furniture and interior decorations.

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Introduction

Naturally endowed with different agroecological zones, Ethiopia is suitable for ruminant livestock production estimated at 54 million cattle and 49.5 million sheep and goats (CSA 2013). According to Asfaw and Mohamed (2007), national annual off-take for cattle, sheep, and goats are 10, 35, and 38%, respectively. As per this ratio, 5.4 million hide and 18 million skins are produced annually. The study made by Zulfikar (2012) at ELICO (Ethiopian Leather Industry Corporation) indicated that from the processing of 7251 ton of cattle hide and sheep skins annually, the tannery generates a total of 4048.96 ton of solid waste from beam house, tanning, re-tanning, and finishing processes which is equivalent to 55.8% of the raw hide and skin processed. Therefore, Ethiopia is one of the most promising leather producing countries in Africa, and it is indicative from this single work that it generates significant amount of solid leather waste which is dumped to the landfill by incurring cost of transportation.

The leather industry, although it is the renowned one in world leather trade, is held responsible for its negative environmental externality. The industry is highly environment polluting sector by generating organic and inorganic pollutants. The waste generated during the operation and utilization process of leather can be solid, liquid waste and/or release of gas that pose a major challenge to the environment and the ecosystem (John Sundar et al. 2011). Solid waste generated from tanneries and leather goods industries includes mainly skin trimming, chrome shaving, buffing dust, finished leather scraps, and used leather waste (i.e., the waste from leather products discarded once used up) (Zulfikar 2012). Improper disposal of the leather waste causes environmental pollution (Assamoi and Lawryshyn 2012). Therefore, proper optimized utilization of the leather waste into value-added end products will be a promising solution (Sekar et al. 2007). Leather waste emanated from used leather products and finished leather scrap is mainly composed of highly ordered type I collagen fiber (Sastry et al. 2005). According recent estimates, about 20–30% leather is discarded as waste during leather goods and footwear manufacturing process (Senthil et al. 2015). Moreover considerable amount of used leather products for instance pairs of chappel uppers, shoes waste, old bags, and end products of leather industry constitute to major solid waste (Kanagaraj et al. 2006). Sastry et al. (2005) have prepared several consumer products such as insoles, chappel uppers, keychain holders, light hand bags, and wallets using leather-like material (LLM) from chrome shavings. Such preparations require careful choice of plant fibers (PFs) which are renewable and sustainable resources (Gurram et al. 2016). Moreover, Senthil et al. (2014)

reported that preparation of regenerated leather from finished leather waste and plant fibers (PFs) is economical, helps in reducing environmental pollution, and enhances its mechanical properties.

A composite can be generally defined as a combination of two or more components differing in form or composition on a macroscale, having recognizable interfaces between its distinct phases (Herakovich 1998). Composites are engineered or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct within the finished structure (Ning 2012). Bio-composites are renewable materials comprising of one or more phase(s) derived from a biological origin. The reinforcing agent could be a plant fiber such as sisal, bamboo, cotton, flax, and hemp or the fibers derived from recycled paper waste, wood waste, by-products of food crops, and regenerated fiber. In recent years, various research groups have been involved in the investigations of natural fibers as a constituent of the composites. The growing interest in natural fibers is due to their low cost, production from renewable resources, safer handling, and positive environmental impacts. Cotton, jute, flax, sisal, and hemp are the suitable candidates to replace glass fiber in the composites as environmental-friendly strengthening agents (Xie et al. 2010).

Plant fibers are attractive material for a variety of potential applications (McDougall et al. 1993). Their preference appears to be associated with their low cost, fairly good mechanical properties, high specific strength, nonabrasiveness, eco-friendly and bio-degradability characteristics (Ku et al. 2011). The distinctive features they possessed make the PFs unique and are excellent materials for soil conservation (Rowell et al. 2000), textile applications (Karthik and Murugan 2013), serve as alternate materials especially as wood substitutes in the construction market (Saxena et al. 2008), and as reinforcement for composite materials to produce automotive structural components (Suddell and Evans 2005). When combined with composite materials, PFs provide smooth surface agreeable to be used in footwear, leather goods, and textiles materials (Kalia et al. 2013).

Except the report by Senthil et al. (2014) on the production of value-added products from leather waste in India, no work is done in Ethiopia on the production of useful products from finished leather scrap with plant fibers or composite preparation using natural rubber latex as well as any other binders. Since finished leather scrap and used leather waste material contribute a major portion of solid leather waste, research on the conversion of this waste into useful value-added products for consumer application can be considered as means of income generation as well as an

economically beneficial way of reducing environmental pollution. The objective of the present experimental research is therefore to prepare leather composites, from finished leather waste and compare different plant fiber composites in terms of mechanical, physical and thermal properties using natural rubber latex as a binder.

Materials and methods

Materials

Finished leather scrap (finished leather waste material) was collected from ELICO (Ethiopian Leather Industry Corporation) and from Central Leather Research Institute in Chennai, India, used as source of leather fiber for leather board composite making. Natural rubber latex, ethylene glycol ($C_2H_6O_2$), sulfuric acid (H_2SO_4) purchased from Sastha PLC Chennai, India, were used as adhesive mixes. Plant fibers such as jute (*Corchorus trilocularis* L.), hibiscus (*Hibiscus Cannabinus*), sisal (*Agave sisalana*), palm (*Phoenix dactylifera*), and enset or Ethiopian banana (*Ensete ventricosum*) were collected from market places of Ethiopia (Addis Ababa-Merkato) and India (Chennai and Andhra Pradesh) and used as sources of reinforcement fibers.

Methods

Preparation of leather fiber (LF) and plant fibers (PFs)

Finished leather scrap was cut into small pieces of convenient size to use in the pulverizing machine (length 5–10 cm and width 2–3 cm) using Swing ARM Clicker (Porielli S.20, VIGEVANO-ITALIA) and converted into leather fiber (LF) with the help of Hinged Hammer Pulverizing machine (Sturtevant, SDL868, USA). Similarly, all long uneven plant fibers were cut into small pieces to convert them into smooth and short fibers. The average fiber size ranged between 1.5 and 2.5 cm in length and 0.2–0.7 mm in width according to the procedure of Satyanarayana et al. (1990).

Preparation of recycled leather (RCL) boards

About 300 g of fiberized LF was soaked in water for 24 h and then squeezed manually using mesh, after which 400 ml natural rubber latex, 5 ml of ethylene glycol were added and mixed thoroughly. The final pH was adjusted to be below 5 using diluted 1 M H_2SO_4, the prepared paste was then poured into steel plate size (62 × 62 cm), pressed gently using hand roller to make leveling, and covered by another steel plate. The wet sheet was again pressed using

hydraulic press (Polyhydron 4DL10SGS-10) at a pressure of 1000 PSI (pounds per square inch) for 10 s. The pressed sheet was dried in open air for 2–3 days and plated using hydraulic press at a pressure of 1500–2000 PSI at 60–80 °C for 10 s.

Preparation of leather composite boards

The extracted and fiberized PFs were added to the LF individually in various proportions (10, 20, 30, and 40%) and then mixed in the industrial mixer. Composite boards containing LF and different species of PFs were then prepared separately following the same procedure as that of control board. The details of the composite boards prepared are noted as follows:

1. RCL—composite board made from recycled leather and rubber latex served as a control.
2. RCL-J—composite board made from RCL and jute fiber.
3. RCL-H—composite board made from RCL and hibiscus fiber.
4. RCL-S—composite board made from RCL and sisal fiber.
5. RCL-P—composite board made from RCL and palm fiber.
6. RCL-E—composite board made from RCL and enset fiber.

Characterization of control and composite boards

Recycled leather (RCL that served as control) and RCL-PFs composite boards were characterized for their mechanical properties, thermal stability, thermal transition temperature, formation and changes in the functional groups and surface morphology.

Mechanical properties Mechanical properties were assessed using three dumbbell-shaped specimens of 4 mm wide and 10 mm length. Tensile strength (MPa), elongation at break (%) and stitch tear strength (N/mm) were measured using universal testing machine (INSTRON model 1405) at an extension rate of 5 mm/min. Flexing endurance strength was also assessed using fiber board flexing (TER 74) machine according to (STM 129) test method. Water absorption and desorption (%) capacities of the control and different composite boards were determined according to Sekar et al. (2007).

Physical characterization Fourier transform infrared (FTIR) measurements were taken to determine the formation and changes in the functional groups of composite boards. The spectra were measured at a resolution of

4.0 cm^{-1} in the frequency range of 4000–600 cm^{-1} using Nicolet 360 FTIR spectrometer. Thermogravimetric analysis (TGA) was used to analyze the thermal stability of control and composite boards. Differential scanning calorimeter (DSC) was used for the determination of thermal transition temperatures. All the measurements were taken using STA 449 F3. Required amount of samples (2–3 g) was placed in a platinum pan, and test was carried out in a programmed temperature range of 32–800 °C at a heating rate of 10 °C/min, under nitrogen atmosphere at flow rate of 60 ml/min. Surface morphology of the samples was visualized by scanning electron microscope (SEM Model LEICA stereo scan 440 instruments).

Data analysis

Measurements on physical characteristics of control and composite boards were taken, and mean values were compared between leather and fibers of different plant types used. Descriptive statistics was employed using Statistical Package for Social Sciences (SPSS version 20) software as mean and standard deviation of the four individual experiments ($n = 4$). Origin 8 software was also used for FTIR, TGA, and DSC graphs.

Results and discussion

The mechanical studies of the composite sheets are important because the sheets have to bear the mechanical stress when used by the consumer. The products with good mechanical properties last long and are commercially successful in the market. Keeping these facts in view, mechanical properties of the composite boards prepared in this study were estimated using conventional methods. Mechanical properties such as tensile strength, elongation at break, stitch tear strength, and flexing strength were estimated. Apart from the mechanical properties, the water absorption and desorption properties of the composites prepared were also determined.

Table 1 shows that all RCL-J fiber composites had better tensile strength than the control board (1.85 ± 0.34).

Among the four different samples, sample 3 (20% PF) RCL-J composite boards have optimum tensile strength (2.20 ± 0.27) and flexing index (2.64 ± 0.32). Elongation at break (14.31 ± 2.65) and water absorption (57.86 ± 2.67) results were higher in sample 2 (10% PF), whereas stitch tear strength values (22.57 ± 1.30) and water desorption (85.94 ± 2.15) were greater in sample 5 (40% PF). Water absorption values of sample 3 (20% PF compositions) (25.84 ± 10.87) and sample 4 (30%) (21.90 ± 0.88) did not meet the minimum standard value (i.e., minimum 35%; SATRA: TM 9:1993).

The tensile strength of the RCL-H fiber composite boards as indicated in Table 2 was better than the control board (1.85 ± 0.34). The optimum result in tensile strength (2.35 ± 0.22) and elongation at break (12.03 ± 2.15) were obtained in sample 2 (10% PF) of RCL-H composite, but stitch tear strength of the control board had better value (45.21 ± 11.33) than all the RCL-H composites. Sample 3 (20% PF) and sample 4 (30% PF) had better flexing values of (2.44 ± 0.02 and 2.24 ± 0.14, respectively) which is greater than the value of the control. Except sample 2 (10% PF) all samples meet water absorption requirement for industrial use (i.e., minimum 35%; SATRA: TM 9:1993).

All of the composite boards of RCL-S mixtures had better tensile strength than that of control board (1.85 ± 0.34). Among the four different ratios of RCL-S composite boards, optimum result of tensile strength (3.39 ± 0.49) was obtained in sample 2 (10% PF ratio mixture), whereas elongation at break (16.28 ± 1.00) in sample 5 (40% PF). The stitch tear strength of all the composite mixtures, however, was lower than the control board. The water absorption values of the composites are lower even than the standard value for light use footwear (i.e., minimum 35%; SATRA: TM 9:1993) (Table 3); however, these products can be used for other services like auto interior covers and mouse pads.

Table 4 shows that the tensile strength values of all RCL-P composite boards exhibited better results when compared to the control board (1.85 ± 0.34). From the four proportions of RCL-P composites, sample 4 (30% PF) RCL-P composite possessed optimum tensile strength value (2.74 ± 0.22), whereas the elongation at break value

Table 1 Mechanical properties of RCL-J fiber composite boards

Sample no.	LF/PF (%)	Tensile strength (MPa)	Elongation at break (%)	Stitch tear strength (N/mm)	Water absorption (%)	Water desorption (%)	Flexing index (%)
1	100:00	1.85 ± 0.34	12.01 ± 2.61	45.21 ± 11.33	62.41 ± 6.97	83.29 ± 15.27	2.35 ± 0.40
2	90:10	2.08 ± 0.22	14.31 ± 2.65	22.52 ± 3.68	57.86 ± 2.67	60.03 ± 9.86	2.39 ± 0.06
3	80:20	2.20 ± 0.27	12.20 ± 3.46	16.54 ± 3.97	25.84 ± 10.87	78.8 ± 8.63	2.64 ± 0.32
4	70:30	2.05 ± 0.33	8.75 ± 1.43	21.82 ± 3.25	21.90 ± 0.88	61.30 ± 13.17	0.69 ± 0.01
5	60:40	2.17 ± 0.72	8.08 ± 1.43	22.57 ± 1.30	40.74 ± 1.49	85.94 ± 2.15	2.62 ± 0.05

Table 2 Mechanical properties of RCL-H fiber composite boards

Sample no.	LF/PF (%)	Tensile strength (MPa)	Elongation at break (%)	Stitch tear strength (N/mm)	Water absorption (%)	Water desorption (%)	Flexing index (%)
1	100:00	1.85 ± 0.34	12.01 ± 2.61	45.21 ± 11.33	62.41 ± 6.97	83.29 ± 15.27	2.35 ± 0.40
2	90:10	2.35 ± 0.22	12.03 ± 2.15	25.29 ± 2.98	25.80 ± 5.06	68.29 ± 7.05	1.93 ± 0.01
3	80:20	1.90 ± 0.16	12.00 ± 1.70	31.55 ± 2.40	37.23 ± 8.53	57.05 ± 3.32	2.44 ± 0.02
4	70:30	2.09 ± 0.26	10.89 ± 2.06	31.76 ± 4.81	49.27 ± 1.91	62.48 ± 17.18	2.24 ± 0.14
5	60:40	2.00 ± 0.45	6.61 ± 0.49	20.05 ± 5.35	35.52 ± 1.14	82.46 ± 8.35	0.93 ± 0.06

Table 3 Mechanical properties of RCL-S fiber composite boards

Sample no.	LF/PF (%)	Tensile strength (MPa)	Elongation at break (%)	Stitch tear strength (N/mm)	Water absorption (%)	Water desorption (%)	Flexing index (%)
1	100:00	1.85 ± 0.34	12.01 ± 2.61	45.21 ± 11.33	62.41 ± 6.97	83.29 ± 15.27	2.35 ± 0.40
2	90:10	3.39 ± 0.49	14.36 ± 5.20	21.33 ± 0.88	10.74 ± 3.75	78.30 ± 4.68	2.40 ± 0.47
3	80:20	2.63 ± 0.13	10.89 ± 3.51	39.46 ± 3.37	17.02 ± 1.06	76.72 ± 0.16	2.76 ± 0.62
4	70:30	2.37 ± 0.56	11.00 ± 4.92	33.54 ± 1.65	13.5 ± 2.77	8307 ± 1.97	2.66 ± 0.72
5	60:40	2.87 ± 0.25	16.28 ± 1.00	32.01 ± 4.92	29.24 ± 6.46	74.02 ± 3.39	2.88 ± 0.02

Table 4 Mechanical properties of RCL-P fiber composite boards

Sample no.	LF/PF (%)	Tensile strength (MPa)	Elongation at break (%)	Stitch tear strength (N/mm)	Water absorption (%)	Water desorption (%)	Flexing index (%)
1	100:00	1.85 ± 0.34	12.01 ± 2.61	45.21 ± 11.33	62.41 ± 6.97	83.29 ± 15.27	2.35 ± 0.40
2	90:10	2.60 ± 0.36	14.45 ± 3.61	26.52 ± 3.80	30.90 ± 2.96	77.71 ± 0.22	2.80 ± 0.14
3	80:20	2.66 ± 0.09	17.75 ± 1.50	32.50 ± 3.55	29.65 ± 8.24	75.19 ± 0.98	2.35 ± 0.28
4	70:30	2.74 ± 0.22	9.50 ± 0.80	23.83 ± 1.75	24.45 ± 4.32	82.13 ± 3.08	2.35 ± 0.33
5	60:40	1.99 ± 0.31	11.53 ± 1.62	30.62 ± 2.84	31.00 ± 1.32	77.54 ± 5.28	2.70 ± 0.37

(17.75 ± 1.50) was higher in sample 3 (20% PF) ratio. Samples 2 (10% PF) and 5 (40% PF) composites showed better flexing indexes (2.80 ± 0.14 and 2.70 ± 0.37, respectively) and comparatively better water absorption values (30.90 ± 2.96 and 31.00 ± 1.32, respectively) than those of other composites.

Results in Table 5 indicated that all RCL-E composite boards have better tensile strength values than RCL control board. Out of the four different RCL-E composites, sample 2 (10% PF mix) exhibited optimum tensile strength (2.91 ± 0.06), elongation at break (27.84 ± 0.82), and stitch tear strength (78.03 ± 18.46) followed by sample 3 (20% PF) (70.15 ± 8.68%). Except sample 5 (40% PF mix) all RCL-E composite boards have better flexing index than the control board.

As shown in Fig. 1, four characteristics, i.e., tensile strength, elongation at break, stitch tear strength and flexing strength of the composite boards prepared are compared based on their average values. RCL-S has greater average tensile strength value followed by RCL-P, RCL-E, RCL-H, RCL-J and control; in the case of elongation at break, the values are in decreasing order—RCL-E > RCL-P > RCL-S > control > RCL-J > RCL-H; in case of stitch tear strength, the values observed are in decreasing order, i.e., RCL-E > RCL-S > RCL-P > RCL-H > RCL-J; flexing strength values have shown a decreasing order, RCL-E > RCL > RCL-P > control > RCL-J > RCL-H. Of all plant fibers, RCL-E had better average stitch tear strength value (53.15) even than the control (45.21). As suggested by Sun et al. (2004), the higher tensile strength values of the composites might be attributed to the presence of high concentration of lignin in the plants. Sekar et al. (2009) had prepared boards using chrome shaving and plant fibers. The tensile properties of the boards prepared in this study are more or less similar; however, stitch tear strength is much higher compared to those prepared by

Table 5 RCL-E fiber composite boards

Sample no.	LF/PF (%)	Tensile strength (MPa)	Elongation at break (%)	Stitch tear strength (N/mm)	Water absorption (%)	Water desorption (%)	Flexing index (%)
1	100:00	1.85 ± 0.34	12.01 ± 2.61	45.21 ± 11.33	62.41 ± 6.97	83.29 ± 15.27	2.35 ± 0.40
2	90:10	2.91 ± 0.06	27.84 ± 0.82	78.03 ± 18.46	13.70 ± 1.78	68.43 ± 8.95	3.36 ± 0.17
3	80:20	2.65 ± 0.21	17.75 ± 3.38	70.15 ± 8.68	15.79 ± 2.55	70.24 ± 1.63	3.61 ± 0.16
4	70:30	2.78 ± 0.24	19.12 ± 2.07	39.35 ± 5.73	28.96 ± 13.89	66.51 ± 8.74	3.05 ± 0.00
5	60:40	1.91 ± 0.13	14.98 ± 0.83	35.07 ± 6.11	20.18 ± 2.21	55.74 ± 7.49	1.85 ± 0.49
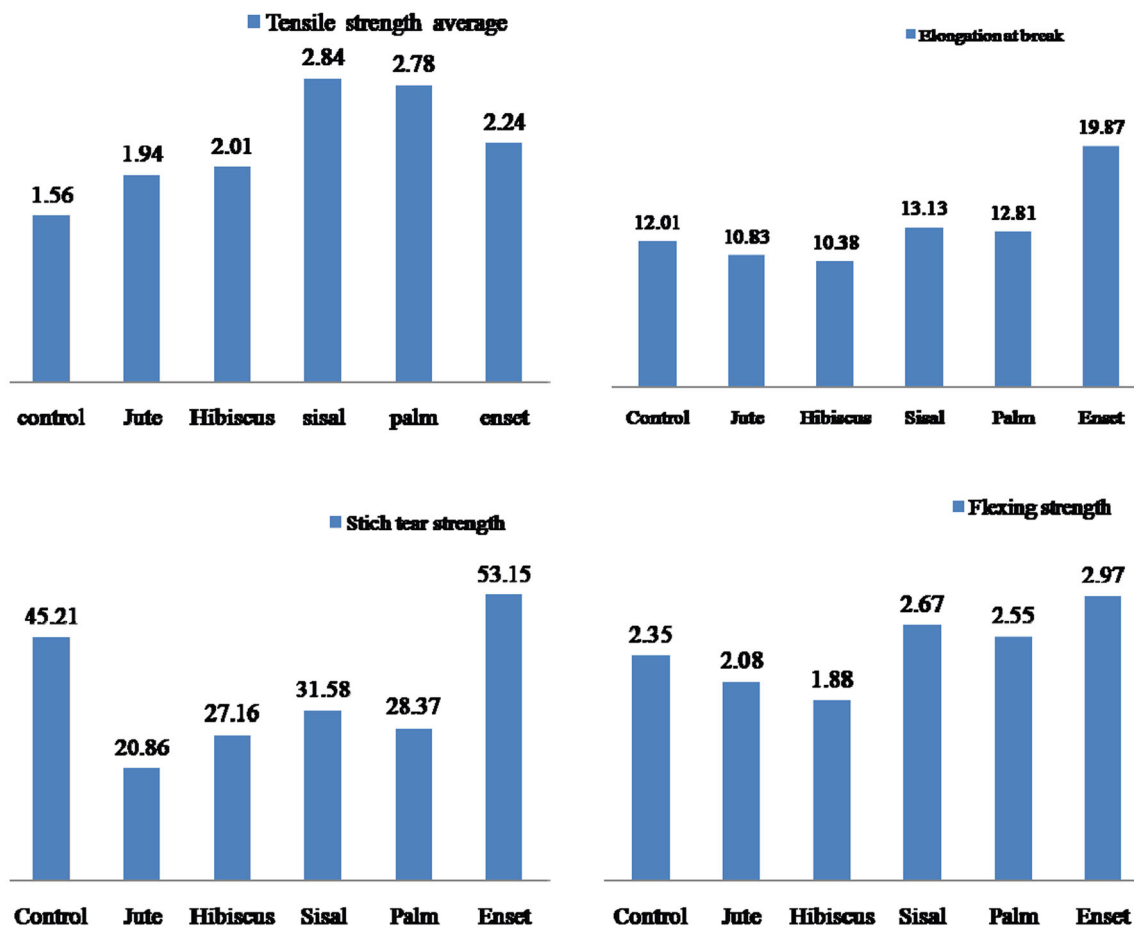
Fig. 1 Comparison of the physical properties of composites prepared

Sekar et al. (2009). The reason for this difference might be due to variation in plant species and finished leather fiber or nature of the binders used. Though difference in tensile and elongation at break among the different plant fibers is observed (i.e., better tensile strength value of RCL-S and better elongation at break, stitch tear strength and flexing values of RCL-E), we can envision that it is possible to prepare products such as insoles, chapel-uppers, wallets, light hand bags, mouse pads, false roofing, wall partitioning, components of furniture and interior decorations from these waste materials.

As presented in Fig. 2, the pictures show the finished leather boards made using leather fiber with plant fibers of jute, hibiscus, sisal, palm and enset with natural rubber latex as binder. In Fig. 2 (a–f), showed the pictures of smooth surfaced finished leather boards compared with the control. The obtained final product can be used as a value added consumer product, and the work of present study
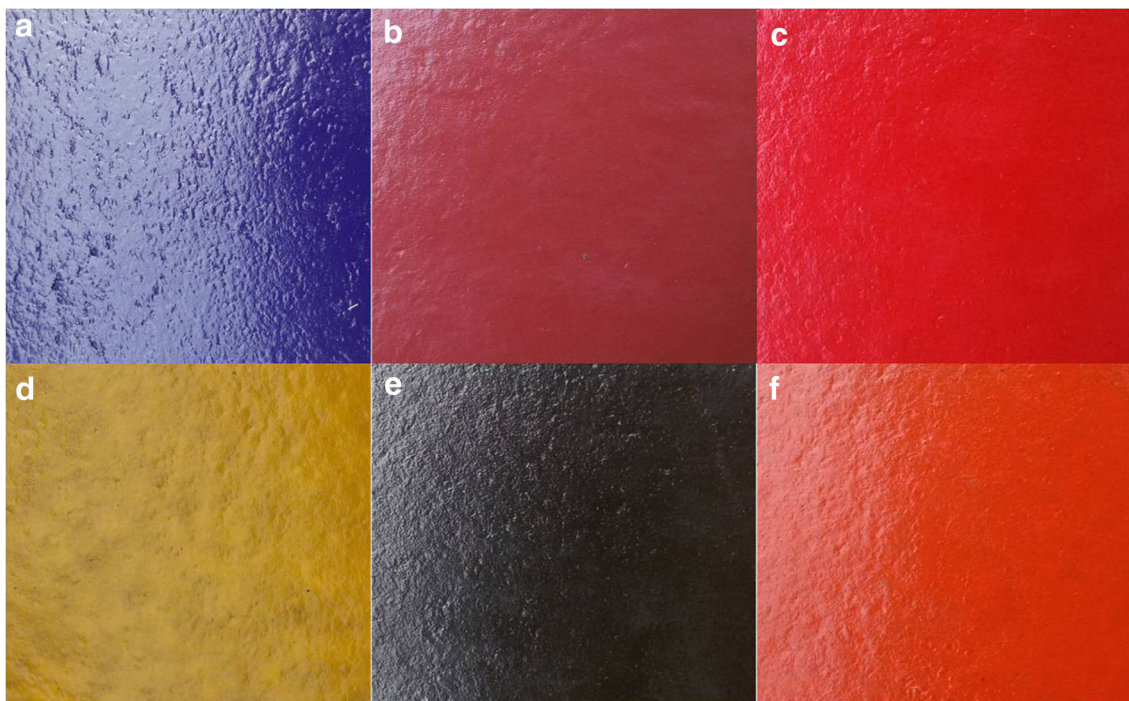
Fig. 2 The pictures of finished leather boards made using the different PFs. **a** Control board; **b** RCL-J composite board; **c** RCL-H composite board; **d** RCL-S composite board; **e** RCL-P composite board crust; and **f** RCL-E composite

was almost similar to the previous works done by Senthil et al. (2014).

Scanning electron microscope

The scanning electron microscope (SEM) images of the samples are shown in Fig. 3. Figure 3a shows the SEM image of control. In this picture, the leather fibers along with the adhesive/binder are seen. The network of fibers adhering with the NRL is clearly seen. The diameter of the individual fibers is more or less the same. This confirms the composite nature of the leather fiber. The SEM picture of RCL-J reveals the binding of NRL with jute fibers and leather fibers. The width of jute fibers (742 μm) seems to be more than that of RCL fiber (166 μm). The composite nature of this sample is evident. In the SEM picture of RCL-H, the microfibers (766 μm) are clearly seen. The combination of leather and hibiscus fibers bonded with NRL is apparent. The composite nature of RCL-S (370 μm) is clearly seen. It was looking that the fibers of leather and sisal are embedded in the NRL. The porosity also seems to be less in this composite. The SEM picture of RCL-P reveals the blend of leather and palm fibers along with NRL. Porosity of composite is visible. In the RCL-E composite, the micro fibers (324 μm) are seen as a bundle. In the fibers of enset, a beautiful blend of leather, enset and NRL is seen and porous nature of the composite is also clear. Almost all composite boards prepared in this

experiment exhibited in their SEM pictures, revealed composite nature, intermingling of the fibers along with NRL, and no difference is observed among the samples in their SEM characteristics. Sekar et al. (2007) prepared composite boards using chrome shaving and various binders. The SEM pictures in the present study are more or less similar to those of Sekar et al. (2007).

Fourier transform infrared studies

The Fourier transform infrared (FTIR) spectra for the samples are shown in Fig. 4. The FTIR spectrum of control board shows the amide bonds of collagen fibers at 1643, 1544, and 1238 cm^{-1} representing amide I, II, and III, respectively (Ramnath et al. 2012). Strong absorption between 3600 and 3200 cm^{-1} region results from superimposed –OH and NH_3^+ stretching bands. A strong and sharp peak is observed at 2933 cm^{-1} representing C–H of rubber latex. A broad peak around 1080–1000 cm^{-1} represents bonded –OH groups in the sample.

FTIR spectra of RCL-J composite sample show a broad peak from 1038 to 1670 cm^{-1} representing C–O–C and C–O stretch (primary and secondary hydroxide groups) and bonds belonging to the glucoside linkage and possibly to due to lignin(Sekar et al. 2009). The peak at 1445 cm^{-1} in this spectrum represents H–CH and O–CH in plane bending vibration. The peak at 1228 cm^{-1} represents –C–H bending at C-6 in the cellulose molecular structure. The FTIR
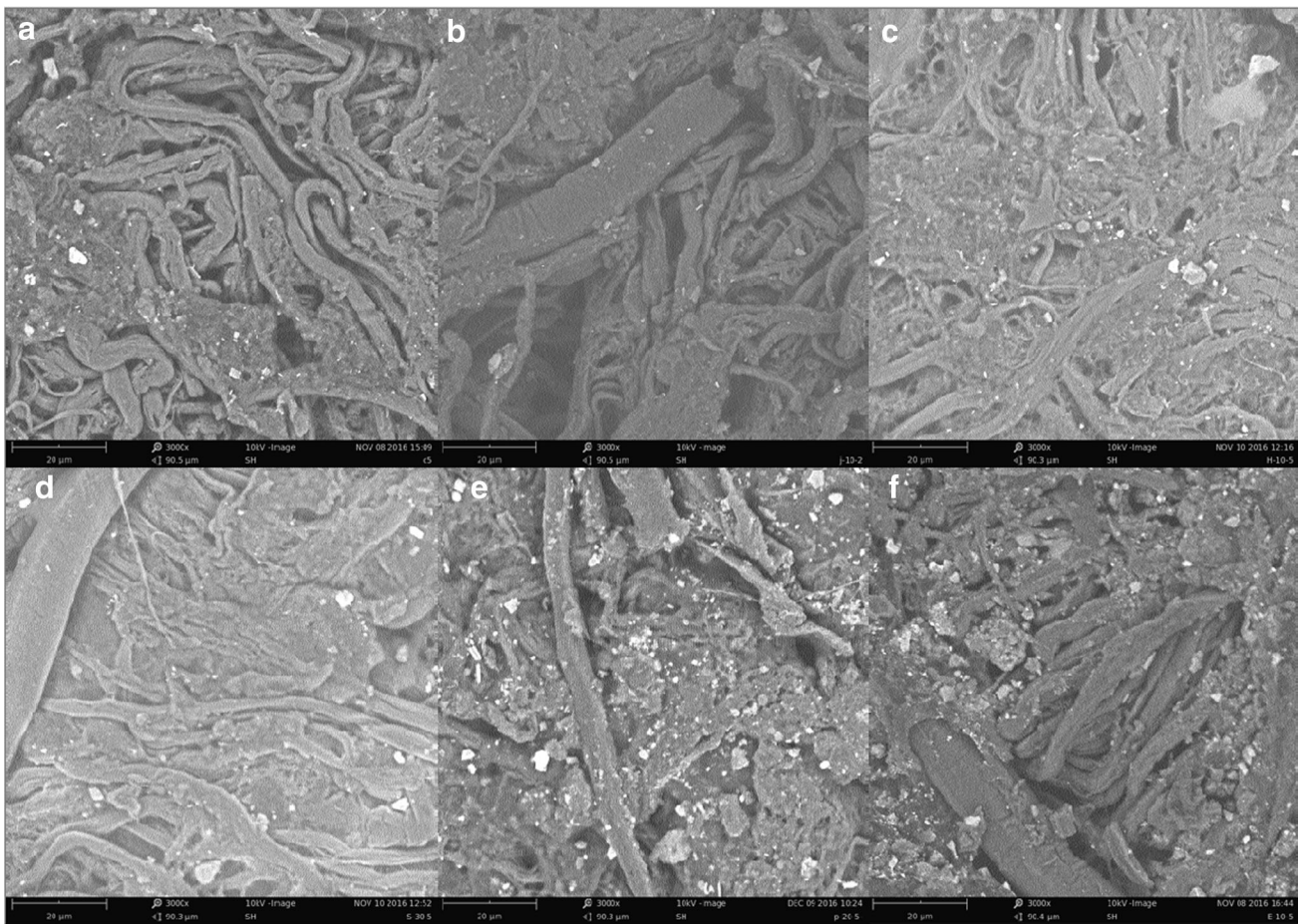
Fig. 3 Scanned electron microscope images of **a** control; **b** RCL-J; **c** RCL-H; **d** RCL-S; **e** RCL-P; **f** RCL-E

spectrum of RCL-H shows similar trend to the RCL-J composite in Fig. 4b, c. However, we can see in the plane – CH bending at 1374 cm^{-1} (Sekar et al. 2009). The spectra of RCL-S, RCL-P and RCL-E in Fig. 4d–f show more or less similar pattern. This is due to the similar nature of cellulose in all the samples representing collagen and cellulose.

Thermogravimetric analysis studies

The TGA reveals loss of the weight of materials with the increase in temperature. In the present study, samples of the control and composite boards were subjected to TGA from 32 to 800 °C. In the control, a two-step weight loss was occurred as shown in Fig. 5a. First weight loss (20%) was occurred up to 290 °C, and this is due to loss of free water and bound water in the sample. The second major weight loss (63%) occurred between 290 and 488 °C, and this weight loss is due to the protein/collagen degradation in the sample. Around 6.4% of the residue was observed at 800 °C.

In the case of sample RCL-J in Fig. 5b a three-step weight losses have occurred. The initial weight loss (9%) up to

223 °C is due to the loss of water molecules in the sample. The second major weight loss (63%) that has occurred up to 449 °C is due to protein and cellulose degradation. The third weight loss (26%) up to 800 °C may be due to decomposition of degraded products. Compared to the leather control board, no sudden degradation was observed in the RCL-J. This may be due to the presence of cellulose, hemicelluloses, and lignin present in jute fiber (Flandez et al. 2012).

RCL-H, RCL-S, RCL-P and RCL-E in Fig. 5c–f samples exhibited more or less the similar thermo gravimetric pattern. However, a residue of 10.3% was observed in the case of RCL-P. This may be due to the more lignin content in the palm plant fiber.

Differential scanning calorimeter studies

Differential scanning calorimeter (DSC) is used for the determination of thermal transition temperatures like Tg (glass transition temperature), Tm (melting temperature), and Tcl (crystallization temperature). The DSC thermogram control sample in Fig. 6a exhibited two endothermic
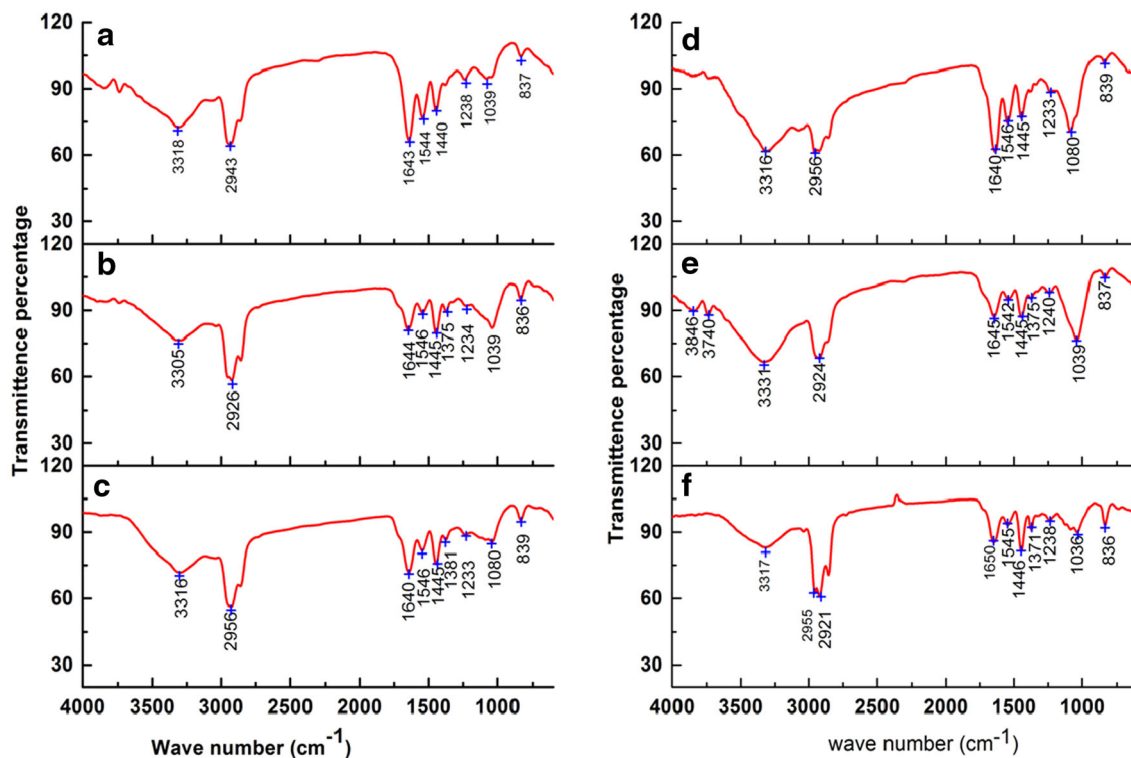
Fig. 4 FTIR results of RCL-plant fibers composite board **a** control; **b** RCL-J; **c** RCL-H; **d** RCL-S; **e** RCL-P; and **f** RCL-E

peaks: Initial endothermic peak (Tm_1) appears at 109.5 °C, and another peak (Tm_2) appears at 311.5 °C. The initial endothermic peak may be due to bound water molecules present in the control sample, and the other melting peak (Tm_2) is related to denature of leather structure in the control sample.

We have incorporated different weight percentage of fiber contents in the composite board making process like jute, hibiscus, sisal, palm and enset, and studied their DSC thermogram. The thermograms of hibiscus and enset showed three endothermic transition temperatures. For RCL-H, the initial endothermic peak (Tm_1) appears at 108 °C. This endothermic value is less than the control (109.5 °C). This endothermic value is less than the control (109.5 °C) and in the other two (Tm_2 and Tm_3) endothermic transitions have lower values (187.7 °C and 302.7 °C respectively) than the control were observed fig. 6 (c & f). However, better values at Tm_3 (325.7 °C) were observed for RCL-enset sample. The less value in endothermic transitions may be due to the samples that have more water and volatile contents in the progressive heating than the control board. As shown in Fig. 6b, d, e the endothermic values of other fibers (RCL-J, RCL-S, and RCL-P) have

higher (Tm_1). This may be due the fact that all the fibers were well dispersed in the leather matrix, so that their melting phase has shifted to the higher temperature. The second and third endothermic peak values of those RCL composites are also shifted to higher temperatures because of the structural heterogeneity of leather and residual tanning materials that can induce the interactions between fibers and the leather.

Conclusions and recommendations

In conclusion, the RCL-plant fiber composite boards have shown better tensile strength properties when compared to the control sample. In most of composite boards, the flexural strength is better than the control, and the SEM studies have shown the composite nature of the boards. The thermal stabilities of the RCL-PF composites have shown no sudden degradation and are encouraging. In DSC study, most composites showed better endothermic values. Therefore, based on these results, it is concluded that the composite boards prepared can be used as raw material for the preparation of light consumer goods such as chappel
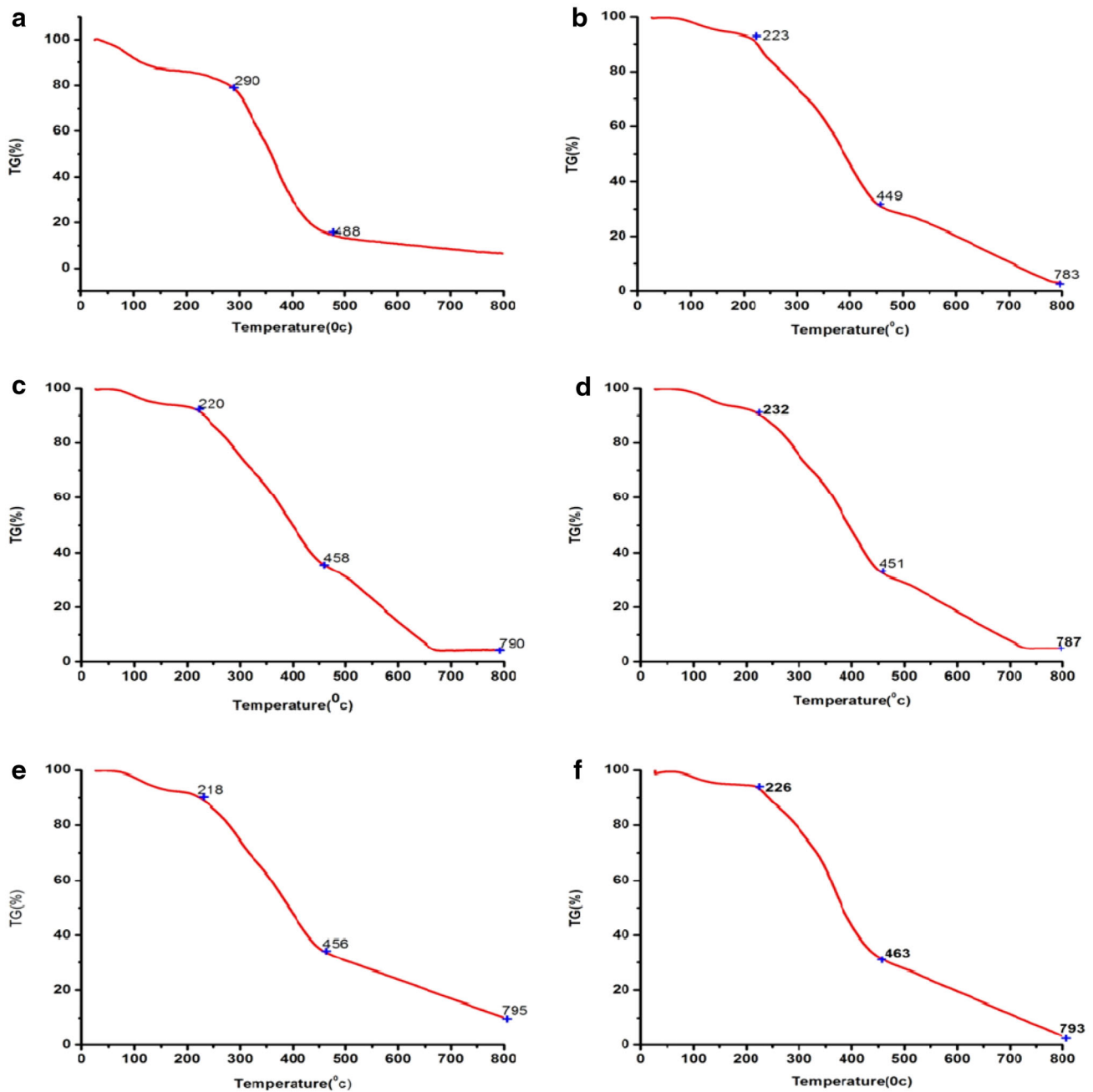
Fig. 5 Thermogravimetric analysis of composite samples a control; b RCL-J; c RCL-H; d RCL-S; e RCL-P, and f RCL-E

uppers, light hand bags, wallets, mouse pads, false roofing, wall partitioning, components of furniture and interior decorations. However, further study on improving the quality in tensile strength, elongation at break, stitch tear strength, water absorption, and flexing strength as well as over all estimates of the economic feasibility of the

processed products, providing estimates of annual mass production and price of waste leather, latex, plant fibers, dyeing agents for finishing, demand and an approached price of composite boards, machine costs, and energy requirement for (cutting, fiberizing, pressing, plating) to make it applicable at marketable level needs to be done.
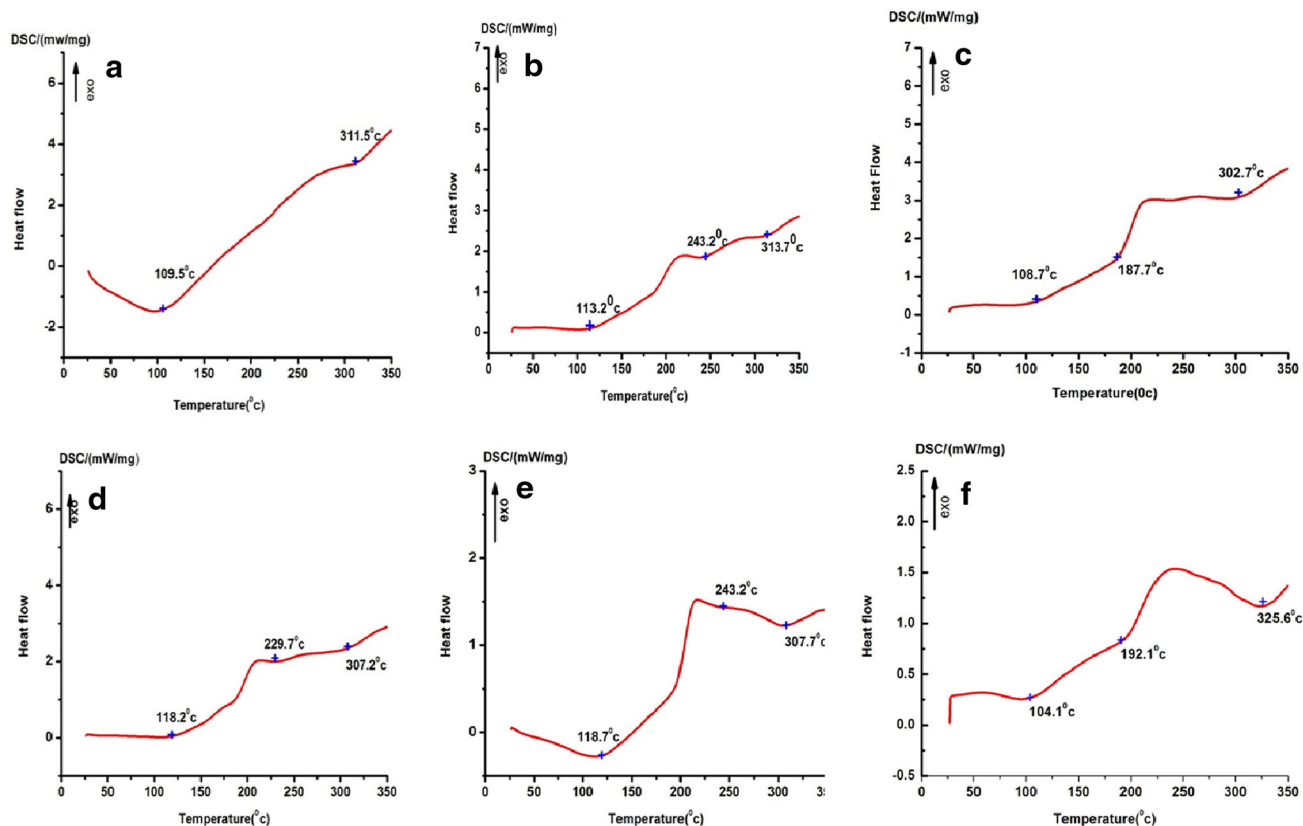
Fig. 6 DSC thermograms of RCL composites **a** control; **b** RCL-J; **c** RCL-H; **d** RCL-S; **e** RCL-P, and **f** RCL-E

Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest.

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