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Development of leather waste composite sheets as a sustainable material for upholstery applications

Rajesh Chengamchetty Murali[a*], Akshaya Raman Murugan[b], Suresh Kumar Duraisamy[a], Sadhanandham Jeevanandham[a] & Kaliappa Krishnaraj[a]

[a]Shoe & Product Design Centre (SPDC), CSIR-Central Leather Research Institute, Adyar 600 020, Chennai, India

[b]Knowledge portfolio management unit, CSIR-Central Leather Research Institute, Adyar 600 020, Chennai, India

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The paper has focused on developing leather waste composites by pulverizing leather dust and manufacturing scraps and mixing them with additives such as polyurethane (PU) and silicone-based polymers to produce sustainable upholstery materials. The composites, particularly the 80/20 PU/leather blend, have exhibited superior mechanical properties, including a tensile strength of 3.0595 N/mm², which has significantly outperformed conventional materials. The composites have demonstrated reduced water absorption, stable electrical properties, and improved fire resistance, with a limited oxygen index (LOI) of 24 and a delayed ignition time of 8 seconds. This innovative approach has addressed practical requirements for upholstery applications while also supporting environmental sustainability by promoting a circular economy and contributing to carbon reduction in the aviation industry.

Keywords: Compression Moulding,Leather waste composite, Sustainable materials, Upholstery

1 Introduction

The process of converting putrescible hides or skins into non-putrescible material is known as leather manufacturing. In the leather manufacturing process, only 150 kg of raw material is converted into leather, leaving the remaining 850 kg as waste[1]. Several studies are being conducted to effectively re-use waste raw materials by processing them into valuable materials such as gelatin. Gelatin is a protein that can be extracted from leather waste. It is used in a variety of products, including food, pharmaceuticals, and cosmetics[2]. Leather waste can also be used to produce fertilizer[3]. This can help to reduce the need for chemical fertilizers, which can pollute the environment. Leather waste can be used to produce reinforcing fillers for plastics and composites[4]. Solid leather wastes generated from tanneries and leather goods industries include skin trimmings, chrome shavings, buffing dust, finished leather scraps, etc. According to the latest estimates, 20–30 % of leather is discarded as waste during foot wear production. Also, enormous amount of used leather products such as chappals, shoes, bags, etc. and end products of leather industry constitutes to major solid wastes[5]. Improper disposal of these leather wastes causes environmental pollution, and therefore, proper optimized utilization of these wastes into valuable end products will be a promising solution[6,7]. Leather wastes emanated from used leather products and finished leather scraps is mainly composed of highly ordered type I collagen fiber[8]. This leather waste is different from conventional wastes such as chrome shavings, buffing dust or leather trimmings in terms of its physicochemical, mechanical properties[9] and thermal properties[8,10]. Though there are reports on the fabrication of products from leather wastes, the production of useful products is lagging. Furthermore, scraped leather contribute to a major portion of wastes, and therefore research on the conversion of scraped leather into useful value-added products will be an economically beneficial way of reducing environmental pollution. According to UNIDO, the leather waste generated by footwear manufacturing is significantly greater than the consumption[11]. Because of their hazardous nature and inappropriate disposal methods, around 80% of the solid waste produced by the tanning industry during leather manufacturing operations poses a significant risk to the environment[12]. As a result, it is necessary to find methods for consuming leather waste. There is growing concern about the environmental pollution caused by leather waste. For instance, water

*Corresponding author (E-mail: rajeshm.clri@clri.res.in)

contamination poses a significant environmental challenge, impacting both human well-being and aquatic ecosystems. Among the pollutants often found is heavy metals like lead, cadmium, and copper. These harmful substances can result in various health issues including cancer, kidney damage and neurological disorders.

1.1 Assessing Silicone based Tertiary Amine Absorption

Silicone-based tertiary amines (STA) are emerging as a promising alternative to traditional tanning agents in the leather industry. These compounds offer several advantages, including improved environmental sustainability and enhanced leather quality. Silicone-based tertiary amines are known for their efficient adsorption capacity, making them effective in the tanning process. Using silicone-based tertiary amines can help reduce the environmental impact of leather production by providing a cleaner alternative to conventional tanning agents, which often involve harmful chemicals-based aldehyde/chrome[13]. This research work is to examine into the potential of leather dust composite sheets as a promising alternative for upholstery applications. By integrating waste leather powder, typically discarded in substantial quantities, and binding it with a polyurethane resin binder and STA surface modifier/finishing additive, this composite material presents a considerable case for sustainability[14]. The incorporation of waste leather powder as a primary component not only repurposes a by-product of the leather industry but also capitalizes on the advantages of employing natural, bio-renewable materials[15,16]. This deviation from conventional composites reflects the aviation industry's escalating dedication to mitigating its environmental footprint in a scientifically rigorous manner[17]. Moreover, the integration of a polyurethane resin binder and STA surface modifier augments the mechanical properties and durability of the composite sheets[18]. This enhancement not only ensures compliance with stringent safety standards requisite for upholstery applications but also prolongs the material's lifespan, thereby contributing to a more sustainable lifecycle. Essentially, this research project offers insight into a more sustainable future for upholstery applications by proposing a solution that incorporates natural, bio-renewable, and low-carbon materials. By employing leather dust composite sheets, the furniture industry can progress towards a greener and more environmentally conscious approach without compromising on performance or safety standards. The study focuses on the development of composite sheets of waste leather powder, polyurethane resin binder, and STA surface modifier/finishing additive in various ratios. Mechanical properties, water absorption, electrical conductivity, and fire behavior of the composites are meticulously evaluated to ascertain their suitability for upholstery applications. The findings shows that leather dust composite sheets exhibit commendable mechanical strength, resistance to water absorption, stable electrical properties, and promising flame resistance, thereby positioning them as a sustainable and viable option for Upholstery materials

2 Materials and Methods

2.1. Materials

Leather dust collected from the Central Leather Research Institute's commercial tanning unit was used in this study. The samples were dried and stored at room temperature (RT) in polyethylene bags. The moisture content of the investigated materials was estimated to be around 20%, as determined by the sample weight before and after drying at 105°C.The polyurethane emulsion, RU-3901 is an aliphatic polyurethane dispersion with a solid content of 40.0% was procured from Stahl India Private Limited. The STA (FINISH CT 88 E) utilized in this study was sourced from M/s. Wacker Chemie AG, Munich, Germany and it possess active silicone content from 40 – 60%, water solvents around 30 – 50% and surfactants range from 1 – 5%. The particle size of the STA was below 74 μm, with an average of 5.3 μm.

Polyurethane resin and leather buffing dust were mixed according to specified ratios (as detailed in Table 1) and thoroughly blended. Composite sheets were prepared with varying compositions of PU/LW (90/10, 80/20, 70/30, and 60/40). Additionally, STA

Table 1 — Polyurethane resin and leather waste (buffing dust) ratios for composite preparation

Sample Code	Blends Wt./Wt. Ratio
I	PU/LW (60/40)
II	PU/LW (70/30)
III	PU/LW (80/20)
IV	PU/LW (90/10)
I-A	PU/LW/STA (60/40/5)
II-A	PU/LW/STA (70/30/5)
III-A	PU/LW/STA (80/20/5)
IV-A	PU/LW/STA (90/10/5)

(PU: Polyurethane, LW: Leather waste, STA - Silicone-based Tertiary Amine *)*

was incorporated into the composites at a 5/100 ratio (PU/LW/NC) to produce nanocomposites. The resin mixture was evenly distributed in moulds using blades, with a release gel applied to prevent sticking. Thin plastic sheets were placed on top and bottom to achieve a smooth surface finish, and any trapped air was removed by gently pressing the top layer. This process was repeated for each ratio set. After curing at room temperature or a specific temperature, the mould was opened, and the composite part was removed and further processed. The standard cure time for polyurethane-based systems is 15 minutes at room temperature, followed by a 2-hour post-curing step. Figure. 1 illustrates the process flow diagram for preparing the composites using a compression molding machine to create smaller-sized sheets. Subsequently, the prepared composites were cut to size for analysis. Various combinations of polyurethane, leather dust, and STA were evaluated to determine the optimal ratio for achieving desired composite characteristics

2.2 Characterization

2.2.1 Differential scanning calorimetry (DSC)

Differential scanning calorimetry (DSC) was employed to determine the glass transition temperature (Tg) of the composite samples. The DSC analysis was conducted using a NETZSCH DSC 214 Polyma instrument. Approximately, 10-15 mg of the samples are crimped in an aluminum pan and heated from 25°C to 120°C at the rate of 5°C/min under a nitrogen atmosphere.

2.2.2 Thermo gravimetric analysis (TGA)

The thermal stability of polymeric materials was studied by thermogravimetric analysis (TGA), which was performed in STA 449 F3 Jupiter thermal analyser (Netzsch, Germany). The samples were heated from 30 to 600°C at a rate of 10°C/min under a nitrogen atmosphere with a flow rate of 80 mL/min.

2.3 Mechanical properties

2.3.1 Sampling and conditioning

Before conducting physical testing, leather samples were collected from the designated sampling location and conditioned for 48 hours at a standard temperature of 27±2°C and relative humidity of 65±2%. Four samples were taken from Composites for test and the mean values and standard error were calculated and reported using statistical analysis. To test the tensile strength, stitch tear strength, and percent elongation at the break of composites, samples were cut in parallel and perpendicular directions[20,21].

2.3.2 Tensile strength

Tensile strength was evaluated by measuring the force per unit area of a test specimen (N/mm^2) using a Universal Testing Machine (M/s Instron Inc., UK). The width and thickness of the dumb-bell shaped specimen were measured in the centre of the narrow section. The jaw separation rate was kept constant at 100 mm/min. The difference between the initial length of the sample and the length at the time of rupture was used to calculate percentage elongation at break[20,21].

2.3.3 Stitch tear strength analysis

Using the double hole tear method, the stitch tearing resistance was assessed[20]. On the long axis, close to one end, the thickness of the specimen was measured. The specimen's holes were filled with a soft steel wire that was 1mm in diameter and bent into a "U" form such that both ends protruded from the

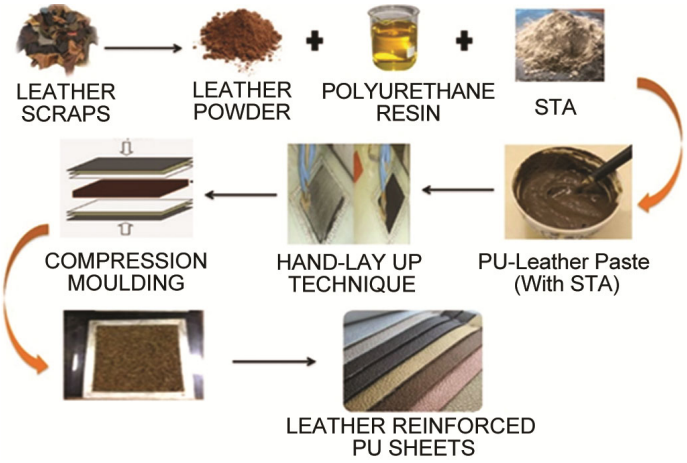


Fig. 1 — The schematic diagram of the preparation of leather waste composite.

flesh side of the specimen. The Universal Testing Machine (M/s Instron Inc., UK) had both ends of the steel wire fastened in one grip and the specimen's free end in the other grip. Till the sample tore, the machine was run at a speed of 25 mm/min. When the test specimen tore, the load was measured, and the stitch tear strength was given in N/mm[20,21].

2.3.4 Flammability test analyses

The flammability test is conducted to evaluate the fire resistance properties of the composites samples according to ASTMD6413. Each sample is subjected to the flammability test four times using a specialized flammability test device. The flammability test device is equipped with avertically fitted Bunsen burner, with a flame height set at 38 mm. Thecomposite test specimens, with dimensions of approximately 125 × 10 × 10 mm^3, are held in a vertical position, and the axis of the burner is positioned below the edge of the specimen. The burner end is kept 40 mm away from the lower end of the specimen. A blue coloured flame, generated by burning liquefied petroleum gas, is used to ignite the test specimen. The time taken for the specimen to ignite is carefully recorded during the test[20,21].

2.3.5 Shore hardness test

Use a durometer to measure the hardness of the leather composite. Shore A is typically used for softer materials, while Shore D is for harder materials. The durometer is pressed into the material, and the hardness is read directly from the scale. As per the standard ASTMD2240, Cut the leather composite into standardized shapes and sizes. Ensure a controlled environment (temperature and humidity) for consistency. Choose a method based on the expected hardness range of the leather composite. Follow the specific protocol for the chosen hardness test, ensuring consistent application of pressure and timing. Record the hardness values and repeat the tests for multiple samples to ensure reliability[20].

2.3.6 Electrical property

The electrical properties of the prepared leather composite samples were characterized using standard techniques.

The electrical resistance (Ω) of each sample was measured using a digital multimeter. The voltage was applied across the sample, and the current passing through it was recorded to calculate the resistance using Ohm's law,

$$(R = V/I).\ R = V / I \quad \ldots (1)$$

where,

- R is the resistance in ohms (Ω)
- V is the applied voltage in volts (V)
- I is the current flowing through the sample in amperes (A)

The inductance (μH) of each sample was measured based on the electromagnetic response and calculated using the measured inductive reactance (XL) and the angular frequency (ω) of the AC signal used in the measurement.

$$L = XL / \omega \quad \ldots (2)$$

where,

- L is the inductance in henrys (H)
- XL is the inductive reactance in ohms (Ω)
- ω is the angular frequency in radians per second (rad/s)

The capacitance (F) of each sample was measured using an LCR meter. The sample was placed between two conducting plates, and the capacitance was recorded based on the charge-discharge characteristics. The capacitance can be calculated using the measured capacitive reactance (XC) and the angular frequency (ω) of the AC signal used in the measurement.

$$C = 1 / (XC \times \omega) \quad \ldots (3)$$

where,

- C is the capacitance in farads (F)
- XC is the capacitive reactance in ohms (Ω)
- ω is the angular frequency in radians per second (rad/s)

The Dissipation Factor (DF) calculated which represents the energy loss in the mate-rial due to dielectric losses. It is calculated using the formula,

$$DF = \tan(\delta) = (Im / Ir) \quad \ldots (4)$$

where,

- DF is the Dissipation Factor
- δ is the loss angle (the phase angle between voltage and current)
- Im is the current component due to the dielectric loss
- Ir is the resistive current component

2.3.7 Moisture absorption study

The moisture absorption test was performed on cured leather samples in accordance with ASTM

D570 using dimension of the samples are 60mm*60mm of samples which were weighed before and after immersion in distilled water for 24 hours. The percentage of moisture absorption value was calculated using the formula,

$$\% \text{ Moisture absorption} = [(W2 - W1)/W1] \times 100 \ldots (5)$$

where, W1 is the initial weight (before absorption) and W2 is the final weight (after absorption)[20,21].

3 Results and Discussion

The adsorption process involves the attachment of a substance to a surface and is widely used in applications such as wastewater treatment, the food industry, and pharmaceuticals. Silicone-based Tertiary Amine, known for its high adsorption capacity due to its molecular structure, demonstrated increased adsorption on leather as the temperature rose. The highest amount of Silicone-based Tertiary Amine absorbed occurred at 70°C. The adsorption rate was also greatest at higher temperatures while remaining constant over time. Notably, the experiment showed that the distribution of Silicone-based Tertiary Amine on leather during adsorption was consistent at regular intervals; however, it also caused the leather to harden over time, a process that intensified at higher temperatures, suggesting more efficient absorption at elevated temperatures. In this study, we aimed to investigate the adsorption of Silicone-based Tertiary Amine on leather and its effects on the physical properties of the leather. The uniform adsorption of Silicone-based Tertiary Amine on leather aligns with previous research that has examined the interaction of amine compounds with various surfaces. This process is believed to be influenced by electrostatic and van der Waals interactions between the amine particles and the substrate surface. Due to its specific molecular characteristics, Silicone-based Tertiary Amine is regarded as an excellent adsorbate for leather, which has a complex surface chemistry. By understanding the adsorption behavior of Silicone-based Tertiary Amine on leather, we can optimize the tanning process and enhance the properties of leather[22]. The increased hardness of the leather from the Silicone-based Tertiary Amine adsorption may be linked to both physical and chemical transformations on the leather surface. The amine particles form a barrier that reduces flexibility and permeability, while also chemically interacting with functional groups on the leather, leading to changes in its mechanical properties. Furthermore, the temperature-dependent adsorption behavior observed suggests that higher temperatures enhance the diffusion of Silicone-based Tertiary Amine into the leather matrix, resulting in greater adsorption[23].

3.1 Thermal analysis

Differential Scanning Calorimetry (DSC) was employed to examine the thermal behaviour of the PU/LW/STA composites, with particular emphasis on the glass transition temperature (Tg). The Tg marks the temperature at which the polymer matrix transitions from a rigid, glassy state to a rubbery, more mobile phase, and therefore serves as an indicator of segmental mobility and network rigidity. For the initial set of blends, the measured Tg values were: PU/LW (60/40) = 130.62 °C, PU/LW/STA (60/40/5) = 117.37 °C, and PU/LW/STA (70/30/5) = 105.00 °C. The progressive decrease in Tg with the incorporation of STA reflects increased free volume and chain mobility within the matrix, indicating a softening effect rather than rigid reinforcement. It is important to note that Tg does not directly represent thermal stability; parameters such as onset of degradation and weight-loss profiles - typically obtained from TGA - are required to assess stability against thermal decomposition. Thus, Tg should be interpreted primarily as an indicator of molecular mobility and processability rather than as a measure of the composite's resistance to thermal degradation. In the subsequent composition series (PU/LW 60/40 to 90/10 with 5 % STA), variations in Tg further highlight the influence of blend composition on thermal transitions (Figure. 2). Notably, samples such as PU/LW/STA (80/20/5) and PU/LW/STA (90/10/5) exhibit higher Tg values (117.37 °C and 124.81 °C, respectively) relative to their PU/LW counterparts without STA, indicating that the combined effect of reduced LW content and the presence of STA leads to a comparatively more rigid network. These results demonstrate that the thermal behavior of the composites is governed by the interplay between PU, LW and STA, where optimizing their ratios can modulate segmental mobility and, consequently, the Tg. However, a comprehensive assessment of thermal stability requires complementary techniques such as TGA to evaluate degradation behaviour beyond the glass transition.

3.2 Thermogravimetric analysis

Thermogravimetric analysis (TGA) was carried out to evaluate the thermal degradation behaviour of the PU/LW/STA composites across different blend ratios (Table 2). All formulations showed a characteristic multi-step mass-loss pattern corresponding to moisture release, PU degradation, and the breakdown

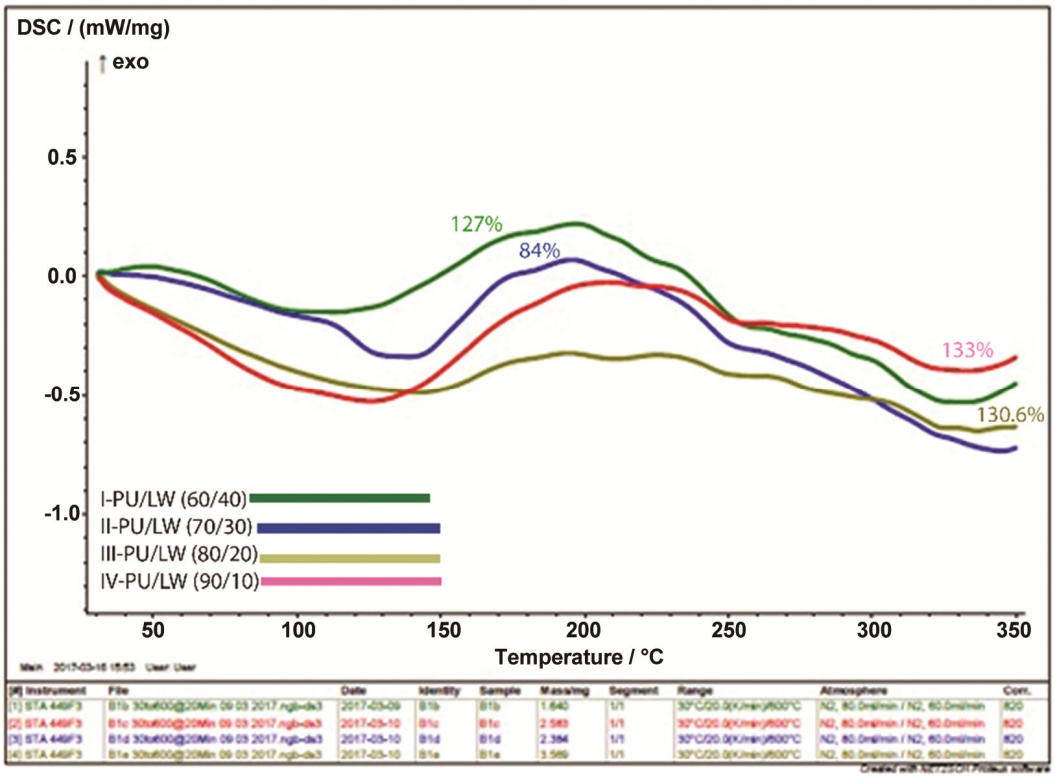


Fig. 2 — Differential scanning calorimetry (DSC) studies.

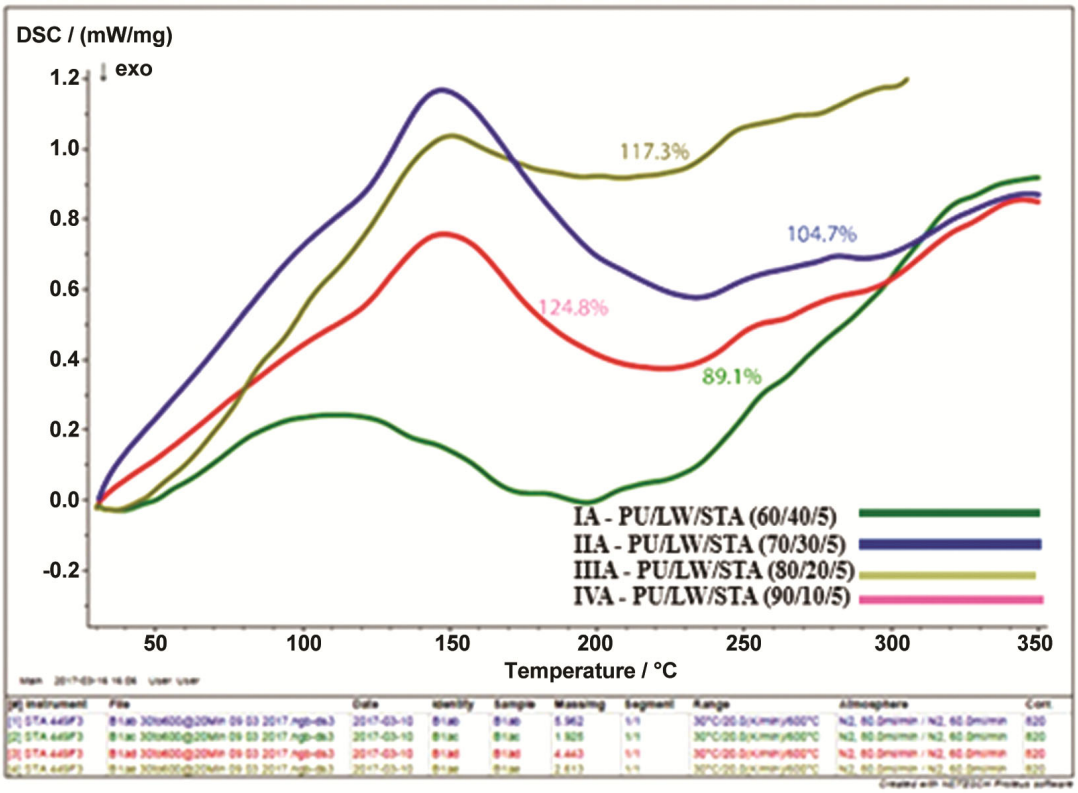


Fig. 3 — Differential scanning calorimetry (DSC) studies.

of collagenous leather fibers. For the PU/LW blends, the initial decomposition temperature (IDT) ranged between 84–131 °C, followed by major degradation events (MDT) occurring between ~307–400 °C, and final decomposition temperatures (FDT) in the range of 388–451 °C. The char yields at the FDT were relatively consistent (approximately 24–26 wt%), with minor variations that do not exhibit a simple monotonic dependence on leather content. These differences are within typical experimental variation for heterogeneous composites and likely reflect the combined contribution of PU, leather residues, and inorganic fractions rather than the leather fraction alone. Upon incorporation of 5 wt% STA, shifts in the IDT, MDT, and FDT were observed across the PU/LW/STA series. While some formulations displayed higher IDT values compared to their PU/LW counterparts, the overall degradation pattern suggests that the effect of STA is composition-dependent rather than uniformly stabilising. The final residues of the STA-containing blends (approximately 13–22 wt%) were generally lower than those of the PU/LW blends, indicating that char formation is influenced not only by leather content but also by the thermal behaviour of PU and the STA additive. Given these trends, the TGA data indicate that the thermal degradation characteristics of the composites are governed by the interplay between PU, LW, and STA rather than by any single component. Therefore, no direct correlation between leather content and residual char can be asserted. Figures 4 and 5

Table 2 — Thermogravimetric analysis properties of the composites

Composite System	DSC	IDT(°C)	MDT(°C)	FDT(°C)	Residue at FDT (%)
PU/LW (60/40)	127.00	399.82	451.34	532.69	24.43
PU/LW (70/30)	84.03	371.68	435.08	524.98	24.61
PU/LW (80/20)	130.62	342.84	404.78	506.79	24.82
PU/LW (90/10)	133.04	307.09	387.90	469.24	25.94
PU/LW/STA (60/40/5)	89.10	236.47	326.06	507.92	22.32
PU/LW/STA (70/30/5)	104.73	236.47	326.06	511.41	21.80
PU/LW/STA (80/20/5)	117.37	239.74	328.33	510.72	19.83
PU/LW/STA (90/10/5)	124.81	245.29	333.60	511.99	13.39

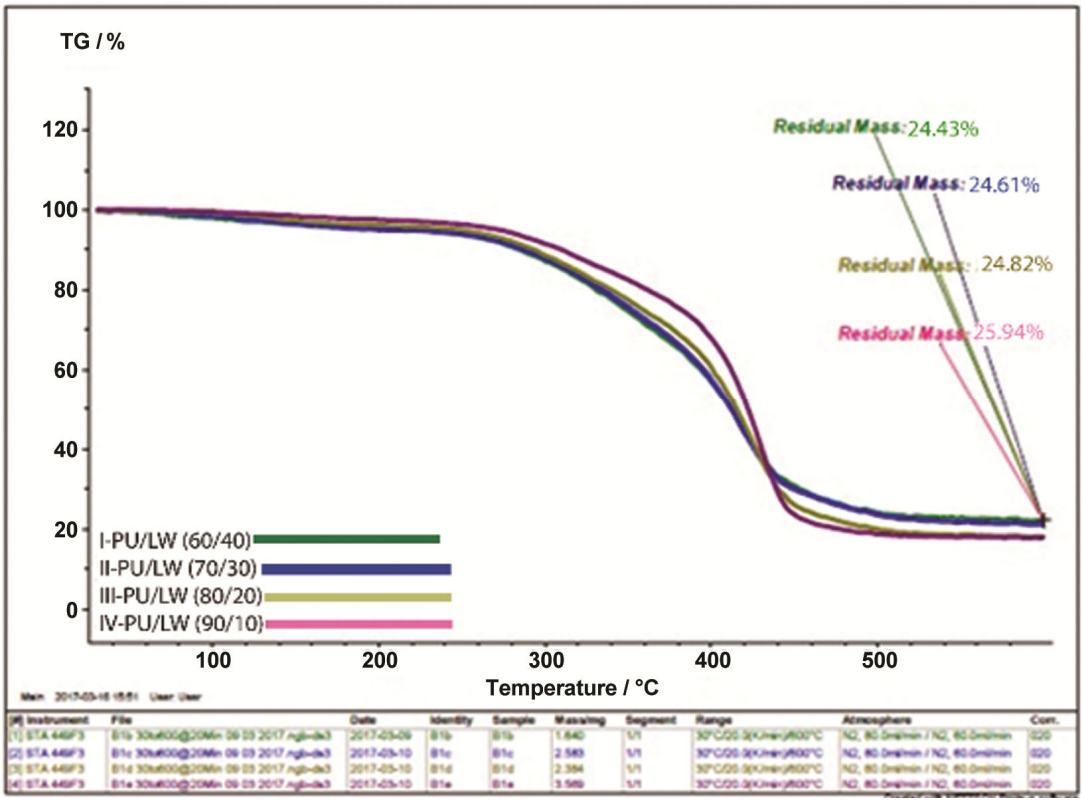


Fig. 4 — Thermogravimetric analysis curves of the composites.

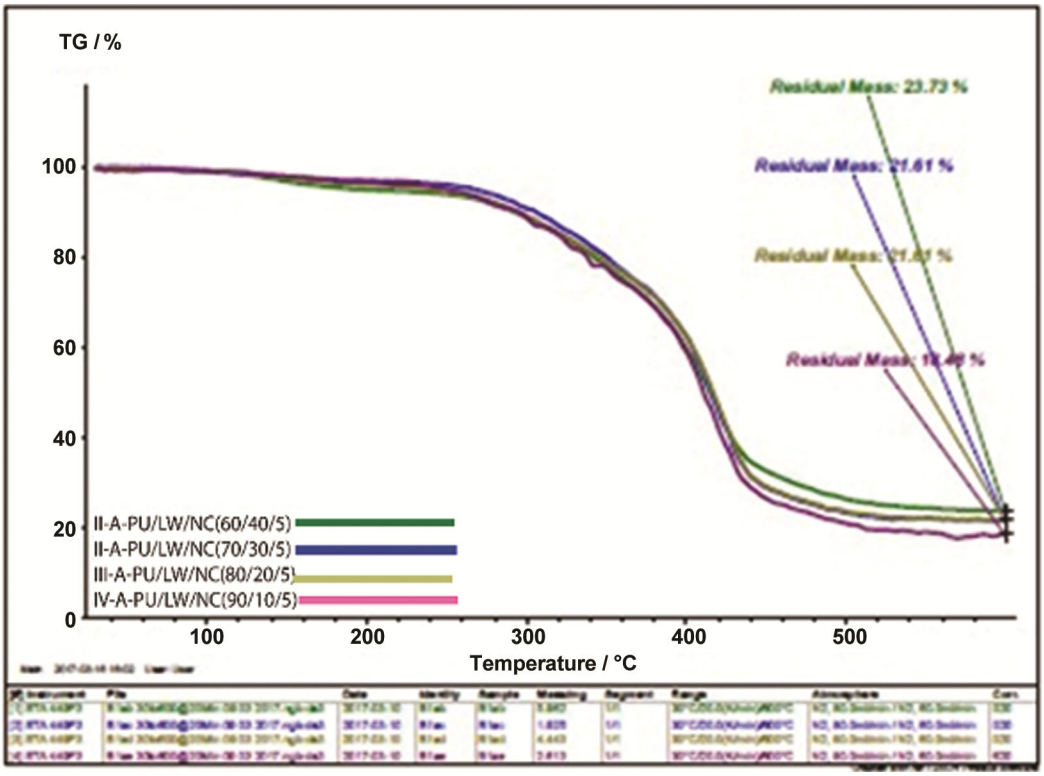


Fig. 5 — Thermogravimetric analysis curves of the composites.

present the TGA curves for the PU/LW and PU/LW/STA series, respectively.

3.3 Mechanical property

3.3.1 Hardness studies

The hardness properties of composite materials composed of PU/LW/STA were examined, considering various blend ratios of PU and LW, along with the incorporation of NC (Figure. 6). Hardness data for the PU/LW blends showed variations with different blend ratios. Sample III (PU/LW 80/20) exhibited the highest hardness value of 47, while Sample II (PU/LW 70/30) demonstrated the second-highest hardness of 42. Sample I (PU/LW 60/40) showed a slightly lower hardness of 43, and Sample IV (PU/LW 90/10) exhibited the highest hardness value of 49 among the PU/LW blends.

Incorporating STA influenced the hardness properties of the composites, demonstrating improved hardness compared to their corresponding PU/LW blends. Sample IV-A (PU/LW/STA 90/10/5) exhibited the highest hardness value of 50, highlighting the potential of STA in enhancing the mechanical properties of the composites. The variation in hardness observed in the PU/LW blends can be attributed to changes in material composition.

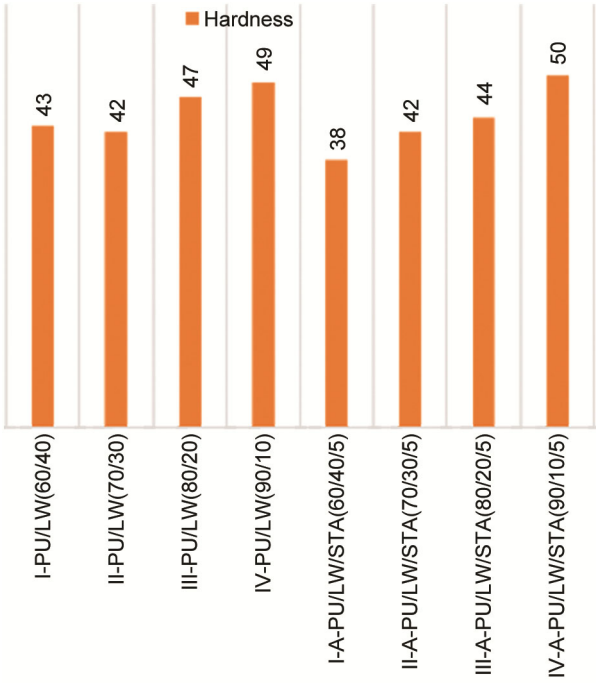


Fig. 6 — Hardness property of the composites.

As the proportion of leather increases, the overall porosity of the composite also increases, potentially leading to slightly lower hardness values since PU

provides flexibility and toughness, while leather contributes to the composite's porosity. The addition of STA enhances the hardness properties of the composites. STA, with its high aspect ratio and strong interfacial interactions with the polymer matrix, reinforces the composite structure and improves its mechanical strength. Consequently, the PU/LW/STA composites demonstrate higher hardness values, indicating enhanced mechanical performance.

3.3.2 Tensile strength property

The tensile strength analysis was conducted on composite materials comprising various blends of PU/LW/STA, and was analysed to understand their performance characteristics (Table 3). Tensile strength and elongation results indicated that the properties of the PU/LW blends varied based on the blend ratios. The PU/LW 80/20 blend demonstrated the highest tensile strength. However, this blend exhibited a relatively low elongation of 32.77% requiring flexibility and resilience. The incorporation of STA into the composite materials improved both tensile strength and elongation properties. The PU/LW/STA, 80/20/5 blend, in particular, displayed the highest combined tensile strength of 3.0595 N/mm² and elongation of 26.85%, indicating a well-balanced mechanical performance. This finding suggests that the addition of STA enhances the overall mechanical characteristics of the composite materials, contributing to their suitability for a broader range of engineering applications.

3.3.3 Vertical flammability studies

Vertical flammability tests carried out as per ASTMD6413 and highlight the fire-resistant nature of the PU/LW/STA 80/20/05 and PU/LW 80/20 composites, both showing a rise in Limited Oxygen Index (LOI) to 24. The PU/LW/STA 80/20/05 composite exhibits a moderately delayed ignition time of 8 seconds, indicative of fire retardancy. These findings showcase promising flame resistance, crucial for aviation safety.

3.3.4 Electrical property

Blends with different weight ratios of PU/LW/STA were subjected to electrical property evaluations (Table 4). For blends without STA (I-PU/LW (60/40), II-PU/LW (70/30), III-PU/LW (80/20), and IV-PU/LW (90/10)), the resistance values range from 1.26E+07 Ω to 1.07E+08 Ω. However, the addition of 5% STA in blends I-A-PU/LW/STA (60/40/5) to IV-A-PU/LW/STA (90/10/5) leads to a consistent decrease in resistance. This indicates that STA enhances the electrical conductivity of the blends since the resistance is inversely proportional to the electrical conductivity of a material. The inductance of the blends also shows sensitivity to STA addition. In most cases, the inductance decreases as the STA content increases. Notably, blends III-PU/LW (80/20) and IV-PU/LW (90/10) show significant reductions in inductance when 5% STA is added. This suggests that STA affects the magnetic properties of the blends. The capacitance and dissipation factor are key parameters reflecting the dielectric behaviour of the blends. With the addition of 5% STA, blends I-A-PU/LW/STA (60/40/5) and II-A-PU/LW/STA (70/30/5) show slight increases in capacitance, while blends III-A-PU/LW/STA (80/20/5) and IV-A-PU/LW/STA (90/10/5) exhibit decreases. The dissipation factor also decreases in most blends with STA, except for blend III-A-PU/LW/STA (80/20/5), where a slight increase is observed. The obtained dielectric constant values increased with increasing leather content in the composites without STA (I to IV), suggesting that higher leather content enhances the charge storage capacity, potentially suitable for electrical insulation applications. With the inclusion

Table 3 — Strength properties of different blends of composites.

3	PU/LW 80/20	3.05	32.77
4	PU/LW 90/10	2.956	22.689
5	PU/LW/STA 60/40/5	2.134	21.97
6	PU/LW/STA 70/30/5	1.72	25.32
7	PU/LW/STA 80/20/5	3.0595	26.85
8	PU/LW/STA 90/10/5	1.89	24.90

Table 4 — Electrical property studies.

Sample	Thickness (mm)	Resistance (Ω)	Impedance (Ω) (Z)	Inductance (μH)	Capacitance (F)	Dissipation Factor
I	2.75	1.65×10^{7}	1.65×10^{7}	-1702.92	1.48×10^{-11}	0.649836
II	2.75	4.77×10^{7}	4.77×10^{7}	-2293.05	1.10×10^{-11}	0.302375
III	2.75	1.26×10^{7}	1.26×10^{7}	-1386.59	1.82×10^{-11}	0.690533
IV	1.75	1.07×10^{8}	1.07×10^{8}	-2465.95	1.02×10^{-11}	0.145484
I-A	1.5	1.05×10^{7}	1.05×10^{7}+j(-964.006)	2.13×10^{-11}	2.62×10^{-11}	0.576569
II-A	2.75	2.61×10^{7}	2.61×10^{7}+j(-1537.44)	1.64×10^{-11}	1.64×10^{-11}	0.371049
III-A	2.75	1.01×10^{7}	1.01×10^{7}+j(-1183.9)	2.13×10^{-11}	2.13×10^{-11}	0.741152
IV-A	2.75	1.76×10^{7}	1.76×10^{7}+j(-1488.55)	1.70×10^{-11}	1.02×10^{-11}	0.531282

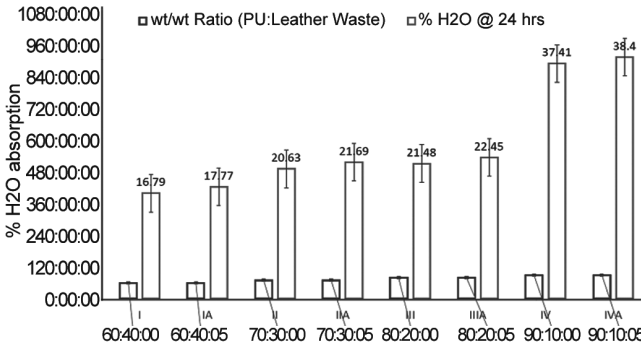


Fig. 7 — Moisture absorption properties of the composites.

of STA in the composites (I-A to IV-A), an interesting trend is observed, where the dielectric constant further increased compared to the corresponding composites without STA. This enhancement can be attributed to the presence of STA, which promotes interfacial polarization effects between the STA particles and the polymer matrix.

3.3.5 Water absorption property

In this study, we investigated the water absorption behavior of different blend ratios of PU and LW, as well as the incorporation of STA, to understand their impact on water resistance properties. PU/LW blends with varying weight ratios (60/40, 70/30, 80/20, and 90/10) were subjected to water absorption tests,16 samples were taken two from each ratio and the test carried out by immersing the samples in water for 24 hours, followed by measuring the percentage of water absorption (Figure. 7) The dimensions of the samples are 60 mm by 60 mm as per the ASTM D 570. The experiments were carried out in triplicate to ensure reproducibility. The water absorption data for the PU/LW blends revealed an increasing trend with higher leather content. Sample IV (PU/LW 90/10) exhibited the highest water absorption (37.41%). In contrast, the PU/LW/STA composites demonstrated reduced water absorption compared to their corresponding PU/LW blends. Notably, Sample III-A (PU/LW/STA 80/20/5) exhibited the lowest water absorption (22.45%), showcasing the potential of STA in enhancing water resistance. The observed increase in water absorption with higher leather content can be attributed to the inherent porosity of leather. The presence of pores in leather facilitates water ingress into the composite structure. Consequently, composites with higher leather content may be more susceptible to moisture-related degradation, which may limit their use in applications exposed to water or humid environments. On the other hand, the incorporation of STA in the composites led to reduced water absorption. STA, with its high surface area and layered structure, forms an impermeable barrier that hinders water penetration into the composite matrix. As a result, PU/LW/STA composites demonstrate improved water resistance. (Table 1) presents the results of the water absorption study for composite materials made from polyurethane (PU) and leather waste, illustrating the impact of leather waste content and STA addition on water absorption. The clear trends observed highlight the influence of both factors on the water absorption behaviour of the composites.

4 Conclusion

This study evaluated the role of silicone-based tertiary amine (STA) as a surface-modifying additive within PU/leather-waste composite systems. The adsorption experiments demonstrated that STA exhibits efficient temperature-dependent uptake onto leather fibres, with higher temperatures promoting increased adsorption. This behaviour indicates that STA interacts favourably with collagenous substrates and can be effectively incorporated into composite formulations. The development of leather-waste composites using pulverised leather dust and manufacturing scraps, combined with PU and STA, highlights a promising route toward value-added utilisation of waste resources. Among the tested formulations, the 80/20 PU–leather blend displayed the best overall balance of properties, including improved tensile performance and reduced water absorption compared with the lower-PU blends. Electrical resistivity and flammability assessments (LOI of 24; ignition delay of 8 s) further support the functional robustness of the material for general upholstery-grade applications. Overall, the findings demonstrate that PU/LW/STA composites offer a viable and more sustainable alternative to conventional upholstery materials. By converting leather waste into functional composite structures, this approach supports circular-economy objectives, reduces landfill burden, and enables the development of environmentally responsible material solutions with potential relevance to sectors requiring lightweight and flexible interior components.

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