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Eco-Friendly Recycling Methods of Finished Leather Wastes- A Review

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Abstract: Leather making is a globally prevalent industry, but it generates various forms of solid waste and wastewater as a byproduct of its production processes. In this review article, the major achievements in the recycling of leather solid wastes are highlighted. Eco-friendly recycling methods for finished leather wastes focus on sustainable practices to reduce environmental impact. These are Natural rubber/leather waste composite foam, NR/CB/Leather composites were developed for use in anti-static flooring and coatings, Green fabrication of leather solid waste/thermoplastic polyurethanes composite, Improving the thermal stability and impact strength of leather wastes-ABS composites via robust experimental design, Leather boards from buffing dust, Polylactic Acid (PLA) Biocomposites Filled with Waste Leather Buff (WLB), Development of a flexible composite from leather industry waste and evaluation of their physicochemical properties and Utilization of chrome-tanned leather wastes in natural rubber and styrene-butadiene rubber blends. These methods minimize waste generation, reduce the need for virgin resources, and promote the circular economy in the leather industry, aligning with environmental sustainability goals.

Index Terms: Composite, leather solid waste, recycling, vulcanization, rubber, flexibility, fibres, textile

1 INTRODUCTION

The global leather industry produces about 1.7 billion m2 of leather, with an estimated market value of about 34 billion euro [1]. Currently, the world's biggest leather producers are located in Asia, with China being the leader of all prominent countries in the leather industry, followed by India and Hong Kong. . Among the EU countries, Italy is the leader in this sector, followed by France, while Germany, as the biggest importer of the EU, imports mostly from Turkey, China, and India [2,3]. The commercially used leather mostly comes from bovine hides with a substantial addition of goat hide and sheepskins. Swine leather on the other hand is much less popular, mainly due to cultural reasons. As a result, only a fraction of the available volume is used for production purposes. Over 85% of leather used for goods production is chrome tanned into the standard wet blue product [4]. Leather making is one of the most widespread industries in the world. The production of leather goods generates different types of solid wastes and wastewater. These wastes will pollute the environment and threat the health of human beings if they are not well treated [5]. Different studies have been developed to seek other options to dispose and utilize these wastes seeking and utilize these wastes [6]. Recycling and chemical treatments can be specifically mentioned as grants. This study focused on Recycling. e regenerated leather composites (RLCs) are promising for the preparation of leather goods and footwear materials in addition to its cost-effectiveness and environmental pollution abatement [7]. Smart and sustainable technologies enable a high degree of recycling with no burden on the environment [8].

2 Recycling Methods

Leather, a versatile material used in fashion, upholstery, and various other applications, generates a substantial amount of waste during its production and processing. This waste includes leather scraps, trimmings, and offcuts, which, if not properly managed, can pose significant environmental challenges. And leather tanning processes cause environmental impact as a result of the generation of solid waste, wastewater, and release of gases. It is estimated that leather processing produces 200 times more waste than total product output [8]. Recycling natural leather waste involves various processes and methods aimed at repurposing and reusing discarded leather materials. These methods are designed to minimize waste, reduce the environmental impact of the leather industry, and often lead to the creation of new products or materials.

2.1 Natural rubber/leather waste composite foam

This is a new approach of recycling the leather waste (shavings) using it as filler in natural rubber foams composites. Various ingredients were used for this. (Natural rubber, The blowing reagent, toluenosulfohydrazina (TSH), with decomposable temperature of 105–110℃ and blowing gas 115cm3/g, leather waste, calcium carbonate, sulfur (S), zinc oxide (ZnO), and stearic acid (SA), The accelerator dibenzothiazyl disulfide (MBTS) and tetra methyl thiuram disulfide (TMTD)). The foams were prepared using different amounts of leather waste (0–60 parts per hundred of rubber) and submitted to morphological (SEM microscopy) and mechanical analyses (cyclic stress–strain compression). The leather waste was analyzed to obtain information about pH value, moisture, ash content, total kjeldahl nitrogen (TKN), and chromium content. The increase of leather shavings on the composite causes an increase of viscosity in the mixture, which is reflected in the foaming process.

Cure characteristic was evaluated using a Teametro ODR model from TEAM Industry, with an oscillating disk of 1° according to ASTM 2084 at a temperature of 125℃ for 10 min. The values of t90 increased in proportion to the amount of leather incorporated in the composites, attributed to the acid characteristic of the waste that inhibits the action of accelerators. Similarly, the addition of leather waste increased crosslinking bonds, which were observed regarding the maximum torque amplified. Variation on minimum torque is related to the influence of leather waste in the viscosity of the composites. The obtained rheometric curve was used to calculate s90 that is the optimal vulcanization time (min) table No 01. And The leather fibers were shredded to diameters of 16 mm using a mill with rotating knives and a 30 mesh sliver from MARCONI

Table. 1: Rheometric Characterization, Obtained Using a Teametro ODR Model with an Oscillating Disk of 1° According to ASTM 2084 at 125℃ for 10 min for Expanded Rubber and for Composites with 20, 40, and 60 phr of Leather Waste at 398 K (125℃)

Composites	M_H (dNm)	M_L (dNm)	ΔM (dNm)	t_{90} (min)
NR	19.1	1.7	17.4	6.18
NR/LW_{20}	21.6	1.8	19.8	6.3
NR/LW_{40}	24.4	1.9	22.5	6.43
NR/LW_{60}	25.3	3	22.3	6.47

Table. 2: Formulation of Foam with Leather Waste

	Samples (phr)			
Ingredients (phr)[a]	NR	NR/LW_{20}	NR/LW_{40}	NR/LW_{60}
Natural Rubber	100	100	100	100
Leather waste	0	20	40	60
Stearic Acid	2	2	2	2
Zinc oxide	4	4	4	4
MBTS[b]	1.2	1.2	1.2	1.2
TMTD[c]	0.2	0.2	0.2	0.2
Sulphur	2	2	2	2
TSH[d]	10	10	10	10
Leather waste (%wt)	0	14.3	25.1	33.44

- Part per hundred parts of Rubber by weight.
- MBTS is dibenzothiazyl disulfide.
- TMTD is tetra methyl thiuram disulfide.
- TSH is toluenosulfohydrazina [9].

Fig. 1. Steps for preparing the natural rubber/waste leather composites (a) Leather waste collect in the tannery. (b) The waste was grounded and sieved to obtain particles of size less than 30 mesh. (c) Natural rubber used in the composite preparation. (d) The natural rubber is masticated out in a conventional laboratory two-roll mill. (e) The final composites of natural rubber/leather allowing different colors choice [10].

Using these ingredients, the compound was made using two-roll mill. (friction of 1 : 1.25 at 65℃) The compounds were vulcanized and foamed via heat transfer process in an electrically heated hydraulic press to mold into microcellular rubber foam; this process involved a simultaneous curing and foaming at 125℃ for 7 min. These conditions were based on a rheometric test of t90. And these compounds were used to investigate their properties. The cyclic compression tests were carried out using the specimens taken with a 1.5 cm of radius and 1.0 cm of edge, and they were submitted to five compression–decompression cycles at 70% of their original height and velocity of 100 mm/min, according to ISO 3386-1:1986.22 For the SEM analysis a Digital Scanning Microscope DSM-960-ZEISS was used. The samples were cut in standard area (0.5 cm 3 0.5 cm 3 0.5 cm) and covered with gold. The samples were analyzed under 340 and 3200 magnifications. Density measurements for the composites (after mixture of vulcanization and foams agents) were carried out evaluating the solid density (before the thermal treatment) and foam density (after the thermal treatment). The measurements were per formed by geometric method, according to ASTM D 1622-

08. Differential scanning calorimetry (DSC) measurements were carried out in DSC from NETZCH 209 model. The samples of about 5 mg sealed in aluminum pans were heated from 100 to 500℃ at a scanning rate of 10℃/min under nitrogen atmosphere. Thermogravimetry (TG) curve and differential thermogravimetry (DTG) were carried out using TGA NETZCH 242C model. The samples of about 5mg were placed in an alumina pan and they were heated from room temperature to 900℃ with a heating rate of 10℃/min.

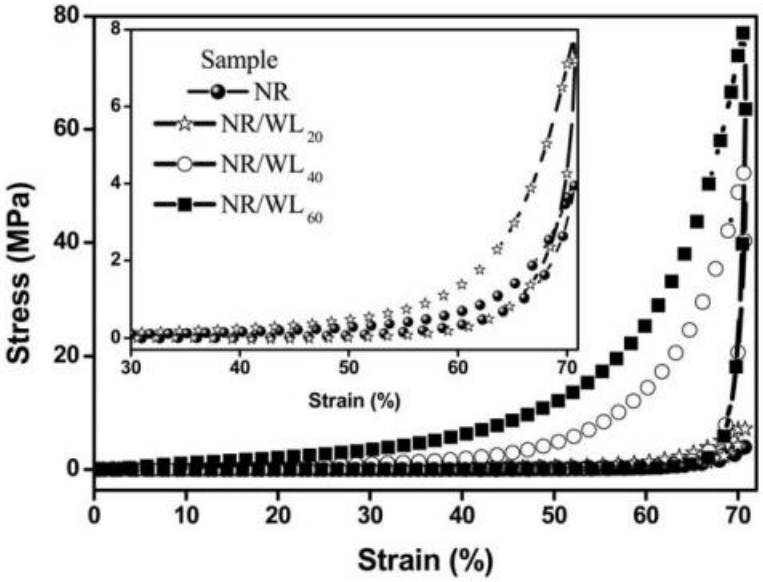

Fig. 2. The first cyclic stress–strain in the case of compression until 70% compression of the original height according to ISO 3386-1:1986, for expanded rubber and for composites with 20, 40, and 60 phr of leather waste.

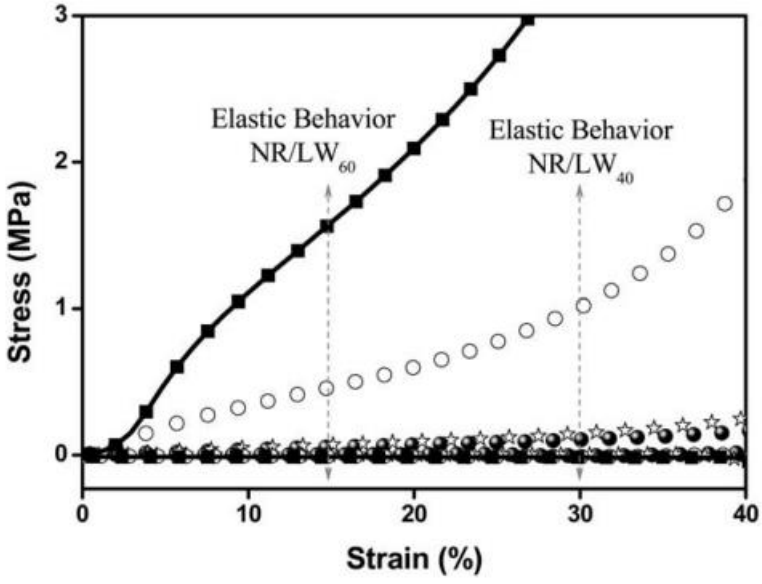

Fig. 3. The cyclic stress–strain in the case of compression until 70% compression of the original height according to ISO 3386-1:1986 for 40 and 60 phr of leather waste (amplification on the viscoelastic behavior).

This results in smaller and fairly uniform cells in the foam. Furthermore, expanded rubber has the biggest cell size, with more than 70% of cell with 1000 mm, while the composite with the higher concentration of leather has around 80% of total number of cells with 100–400 mm. The mechanical parameters were found

to depend on the leather dust concentration. Moreover, the stiffness rises with the increase of leather shavings; consequently, the compression force for expanded rubber was 0.126 MPa as well as the composite with higher concentration of leather was 7.55 MPa.

Table. 3: Hysteresis Loop Area, Calculated by Measuring the Area Related to the Cyclic Compression Curves, for Expanded Rubber and for Composites with 20, 40, and 60 phr of Leather Waste [9].

Sample	Hysteresis (MPa)
NR	0.126
NR/LW_{20}	0.206
NR/LW_{40}	3.459
NR/LW_{60}	7.552

The study's findings revealed that the inclusion of leather waste (Lw) led to improvements in tensile strength and hardness in the resulting composites. These improvements were achieved with good reproducibility and uniform distribution of residual materials throughout the composites, indicating effective miscibility between the components. These enhanced properties suggest that these composite materials could be utilized as raw materials in the manufacturing of various products such as shoes, bags, upholstery, and more. This highlights the potential for recycling leather waste to create useful composite materials, offering both environmental benefits and practical applications in various industries [10].

2.2 NR/CB/Leather composites were developed for use in anti-static flooring and coatings.

The preparation of NR/CB-Leather composites involves combining natural rubber (NR), carbon black (CB), and leather waste to create a versatile material with various applications. NR is sourced from Hevea brasiliensis, while high-purity CB N-330 is used as a reinforcing agent. Chemical additives such as Zinc Oxide, Stearic Acid, 2-Methyl-2-methylmercaptobenzimidazole zinc salt, 2,2 Dibenzothiazyl Disulfide, and Tetramehyltiuram Disulfide are incorporated for vulcanization. The leather waste, originating from tanning processes, contributes to the composites' mechanical stability and resistance to degradation. The mixing procedure adheres to ASTM D 3182 standards, resulting in different composite formulations with varying ratios of NR, CB, and leather waste. These composites are compression molded to create NR/CB, NR/CB/Leather-60 phr, and NR/CB/Leather-80 phr samples, each tailored for specific applications.

To assess their suitability for use in domestic and commercial flooring and coating, the composites undergo chemical attack with sanitizing agents like bleach and disinfectant, followed by chemical and microbiological analyses. The pH tests, difference figure tests, and chromium oxide determination help evaluate the composites' chemical properties. Figure No 03 displays the difference figure values for various composite materials, including NR/CB, NR/Leather, NR/CB/Leather-60 phr, and NR/CB/Leather-80 phr, both with and without treatments using bleach and disinfectant. The key takeaway is that all tested composites exhibited different figure parameters below the ideal threshold of 0.7, indicating their stability and resistance to excessive water exposure. Notably, samples treated with bleach displayed smaller variations in the difference figure, suggesting superior chemical stability compared to untreated samples.

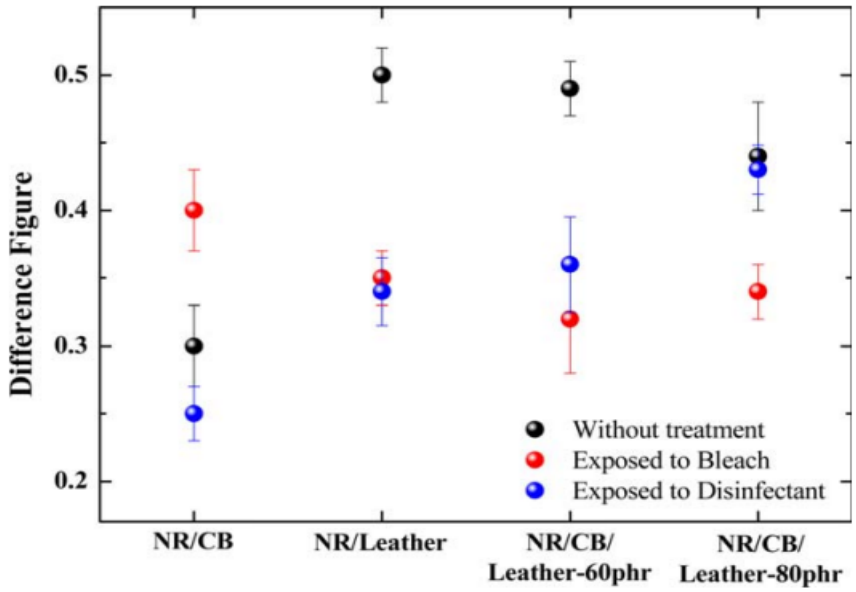

Fig. 4. Difference figure of the NR/CB, NR/Leather, NR/CB/Leather-60 phr, and NR/CB/Leather-80 phr composites without treatment (black lines), samples exposed to bleach (red lines) and to disinfectant (blue lines).

Water absorption tests assess their resistance to moisture, while leaching and solubilization assays determine their environmental impact. The Figure No 04 emphasizes the importance of water absorption assays for composites intended for antistatic flooring. Excessive water absorption can adversely affect mechanical properties, drying time, and electrical conductivity. The study evaluated the water absorption percentages for different composites, including NR/CB, NR/Leather, NR/CB/Leather-60 phr, and NR/CB/Leather-80 phr, both with and without treatment using bleach and disinfectant. The results revealed that the composites, due to the dispersion of leather waste fibers within vulcanized NR and the inherent impermeability of vulcanized NR, exhibited minimal water absorption, all below 0.12%. This indicates their suitability for use in humid environments, even under extremely humid conditions. Comparisons with polypropylene composites reinforced with sisal fibers highlighted the composites' resistance to water absorption, emphasizing their practicality for antistatic flooring applications.

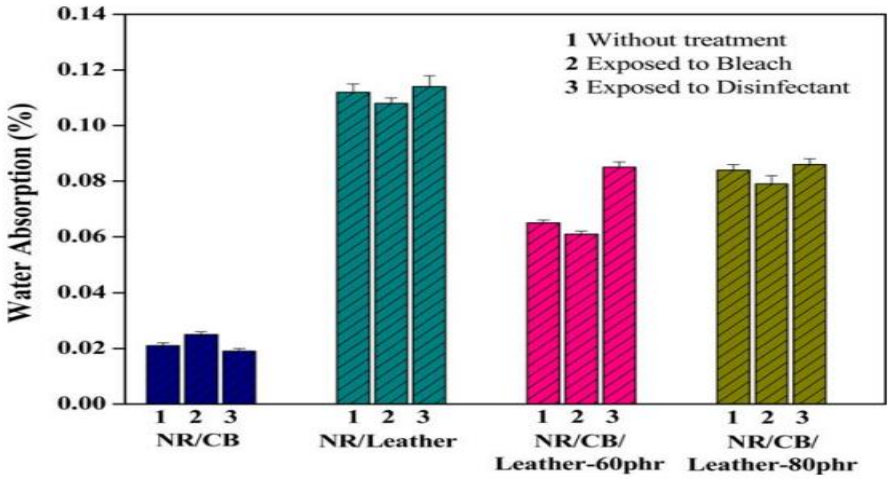

Fig. 5. Evolution of the percentage of water absorption for the compo sites NR/CB, NR/Leather, NR/CB/Leather-60 phr and NR/CB/Leather-80 phr composites without treatment (bars 1), samples exposed to bleach (bars 2) and to disinfectant (bars 3).

Microbiological tests ensure that the composites can withstand potential contamination and remain effective after treatment with sanitizing products. Additionally, the electric, mechanical, and structural properties of these composites have been studied to confirm their suitability for antistatic flooring. Overall, the NR/CB-Leather composites offer a promising solution for a wide range of applications, combining sustainable materials with desirable properties [11].

2.3 Green fabrication of leather solid waste/thermoplastic polyurethanes composite.

In here, discusses the preparation of composite materials (LSW, produced via chrome tanning using pig skins, was pulverized using a self-developed S3M equipment. Thermoplastic polyurethane (TPU) utilized in the study had a hardness of 80 (Shore A), a density of 1.1g/cm³, and a tear strength of 75N/mm.) using leather shaving waste (LSW) and thermoplastic polyurethane (TPU). The LSW is initially pulverized using specialized equipment, and different milling cycles are employed to achieve varying degrees of de-bundling of collagen fibers in the LSW. (Raw LSW was initially cut into fragments using a standard pulverizer. These fragments were subsequently processed in an S3M equipment at room temperature. After each milling cycle, the resulting material was collected, and the equipment was cooled with water. The processed LSW, after multiple milling cycles, was labeled as PMLSn, indicating "Pan-milled Leather Shaving" with a specific number of milling cycles. Raw LSW was also kept for comparison.) These de-bundled collagen fibers are then mixed with TPU to create composite materials with different proportions of LSW. (TPU and PMLSn were mixed in equal mass proportions at 175°C for 10 minutes using a Hapro rheometer. After identifying the optimal milling cycle, composites with varying mass ratios (ranging from 10% to 50%) were prepared under the same conditions. These composites were then shaped into square specimens measuring 100 mm in length and 0.5 mm in thickness. The molding process involved pressing the TPU/PMLSn composites at 175°C under 12 MPa pressure for 5 minutes, followed by an additional 5-minute treatment at room temperature. Subsequently, all samples were stored under controlled temperature and humidity conditions for further experimentation.)

The results show that increasing the milling cycles of LSW effectively de-bundles collagen fibers, leading to improved dispersion and interfacial adhesion with the TPU matrix. The mechanical properties, such as tensile strength, are enhanced as a result. Additionally, the TPU/PMLS9 composite materials exhibit good flexibility and toughness due to improved interfacial adhesion. Dynamic mechanical analysis (DMA) indicates changes in glass transition temperature (Tg) due to the addition of collagen fibers. Thermogravimetric analysis (TGA) reveals the thermal stability of the composites. The water absorption of the materials increases with higher LSW content.

Comparisons with other regenerated or artificial leather materials demonstrate that the TPU/PMLS9 composites exhibit competitive or superior properties, making them a promising material for leather-containing applications. In summary, this study highlights the preparation and characterization of TPU/LSW composite materials, emphasizing the influence of milling cycles on collagen fiber de-bundling and the resulting improvement in mechanical properties and thermal stability. The composites show potential as a high-performance leather-containing material [12].

2.4 Improving the thermal stability and impact strength of leather wastes-ABS composites via robust experimental design.

Various materials and methods were used to prepare and analyze leather waste-ABS composites. (The ABS material was sourced from Toray Plastics Malaysia Sdn. Bnd., while chrome-tanned leather waste (CLW)

was obtained from a Malaysian leather manufacturing industry. Epoxy resin/hardener and acetone were used for surface-coating of the leather fibers.) These coated fibers were then mixed with ABS chips and processed using a twin-screw extruder at different fiber loadings. The resulting composite sheets were used for mechanical testing and morphological examination. (The process involved surface-coating chrome-tanned leather wastes (CLW) with epoxy resin and hardener in a 2:1 ratio, followed by dissolution in acetone at a 1:5 epoxy to acetone ratio (10 wt %). After coating, the material was cured at 80 °C for 24 hours, pulverized into short leather fibers using a milling machine, and then oven-dried at 40 °C for 48 hours. Subsequently, ABS chips, CLW, and epoxy-coated leather (ECLW) were dried at 80 °C for 12 hours under vacuum conditions. These materials were then compounded using a twin-screw extruder at various fiber loadings (5%, 10%, 15%, and 20%) and processed at 240 °C for 5 minutes with a speed of 50 rpm. The resulting extruded strands were pelletized, oven-dried at 80 °C for 3 hours, and compression-molded into 3 mm thick flat sheets. This entire process prepared the materials for mechanical testing and surface morphology analysis.)

Mechanical testing included impact testing, which revealed that the impact strength of the composites increased compared to neat ABS, with the epoxy-coated CLWABS composites showing the highest impact strength. (Drop dart impact tests were conducted using an INSTRON dynatup impact tester (model 9250HV, USA) in accordance with ISO 179 and 180 standards. For each composite sample, five replicate specimens measuring 5 x 5 x 3 mm in dimensions were tested. The reported results represent the average values obtained from these five tests.) The impact properties of uncoated CLWABS and epoxy-coated ECLWABS composites were investigated, revealing significant effects on the strength of ABS. Neat ABS exhibited an impact strength of 0.056 KN/mm², while both uncoated CLWABS and epoxy-coated ECLWABS composites displayed higher impact strengths when compared to neat ABS. The presence of chrome-tanned leather wastes contributed to this improvement. Among the uncoated CLWABS composites, the highest impact strength (0.102 KN/mm²) was observed at a 5 wt.% fiber loading but decreased as fiber loading increased. This decrease in impact strength was attributed to weak interfacial bonding between leather fibers and the ABS matrix, resulting from fiber degradation at the high processing temperature of 240 °C. Conversely, the epoxy-coated ECLWABS composites exhibited the highest impact strength (0.126 KN/mm²) at a 5 wt.% fiber loading, followed by 10 wt.% loading, and decreased with increasing fiber loading. Overall, the improved impact strength of epoxy-coated ECLWABS composites was attributed to the uniform dispersion and distribution of leather fibers, enhancing their mechanical strength.

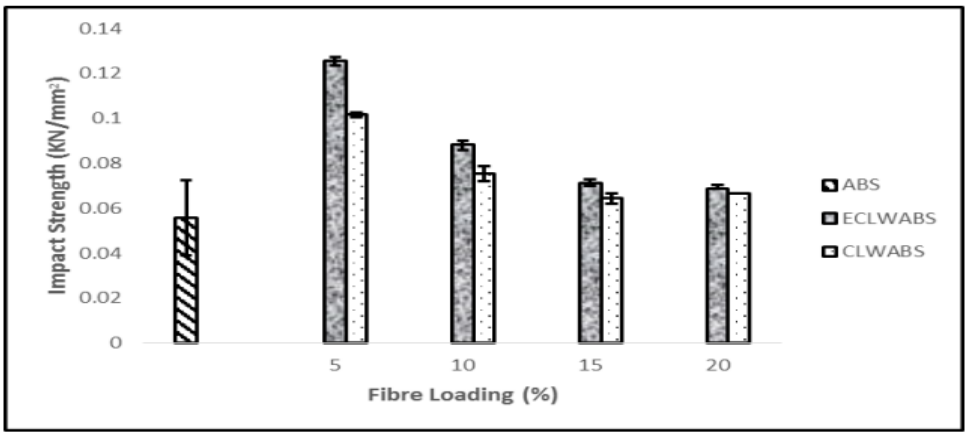

Fig. 6. Effect of epoxy coating and fibre loading on the impact strength of ABS, epoxy coated and uncoated chrome tanned leather wastes short fibre filled ABS composites.

The impact absorbed energy results indicated that neat ABS absorbed less energy (1.93 J) compared to uncoated CLWABS and epoxy-coated ECLWABS composites, which absorbed 5.32 J and 6.39 J of energy at 5 wt.% loadings, respectively. The lower energy absorption in CLWABS composites was due to weak interfacial bonding between uncoated leather waste fibers and the ABS matrix. In contrast, epoxy-coated ECLWABS composites displayed higher energy absorption at 5 wt.% fiber loading, declining as fiber loading increased. These results indicated that the epoxy-coated ECLWABS composites were more effective at absorbing impact energy, reinforcing the significance of uniform fiber dispersion in enhancing the mechanical properties of these composites. This improvement was attributed to the presence of leather waste fibers and the epoxy coating, which enhanced interfacial bonding and mechanical strength. Differential scanning calorimetry (DSC) was used to analyze the thermal properties of the composites, showing that the epoxy-coated composites exhibited lower glass transition temperature (Tg) values than uncoated composites, indicating ductility over a wider temperature range. (Differential scanning calorimetry (DSC) was conducted using a NETZSCH DSC 200 F3 Maia Model from Germany. The purpose of the DSC analysis was to evaluate the thermal behavior and stability of different materials: neat ABS, uncoated leather waste-ABS composites, and epoxy-coated leather waste-ABS composites. The analysis focused on determining key thermal properties such as the glass transition temperature (Tg), melting temperature (Tm), and cold crystallization temperature (Tcc). The testing procedure followed the ASTM D3418-82 standard. The DSC analysis involved a heating process, starting from 30°C and increasing up to 300°C at a rate of 10°C per minute. After reaching the maximum temperature, a crystallization step was performed, reducing the temperature from 300°C back down to 30°C also at a rate of 10°C per minute. Data analysis was carried out using the built-in Proteus analysis software. As a summary, DSC was used to assess the thermal properties and behaviors of the materials, providing important information about their temperature-dependent characteristics.) The thermal properties of ABS, uncoated CLWABS, and epoxy-coated ECLWABS composites at various filler loadings were investigated. (Figure No 07 and 08) Neat ABS exhibited a glass transition temperature (Tg) of 95.4 °C, a melting temperature (Tm) of 214.1 °C, and a crystallization temperature (Tcc) of 227.7 °C. In contrast, uncoated CLWABS composites displayed higher Tg values ranging from 123.5 °C to 246.5 °C and Tm values ranging from 236.5 °C to 256.4 °C at different filler loadings. Epoxy-coated ECLWABS composites, on the other hand, exhibited lower Tg values compared to uncoated composites but higher Tg values than neat ABS. Tm values of both uncoated and epoxy-coated composites were higher than those of neat ABS, with the highest Tm values observed at 5 wt.% filler loading.

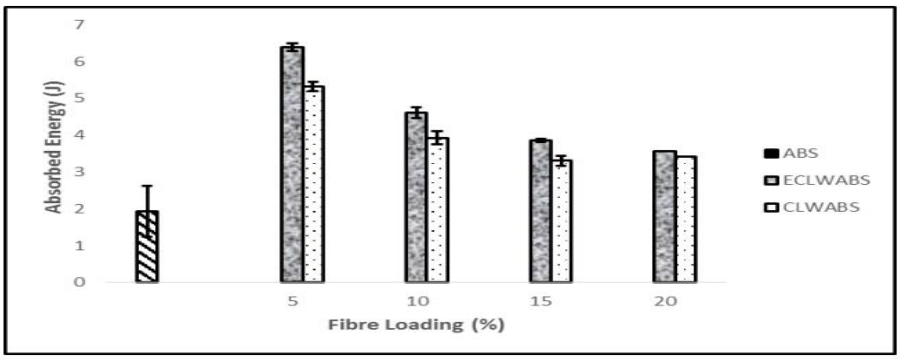

Fig. 7. Effect of epoxy coating and fibre loading on the absorbed energy of epoxy coated and uncoated chrome leather wastes short fibre filled ABS composites.

The thermal transitions of the CLWABS composites generally increased with increasing filler loading, up to 10 wt.%, indicating a high level of compatibility between the leather fibers and the matrix. However, the

cold crystallization temperature (Tcc) decreased at 5 wt.% and 10 wt.% filler loadings but increased with higher filler content, suggesting a higher degree of amorphous regions at higher filler content.

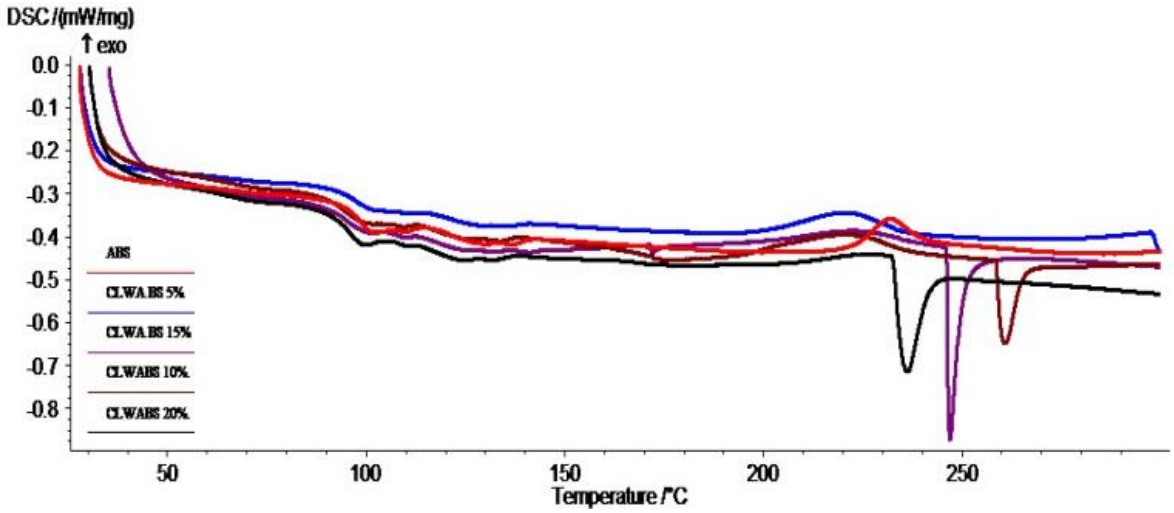

Fig. 8. DSC thermograms of ABS and chrome tanned leather wastes (ECLW) at 5 -20 wt% filler loadings.

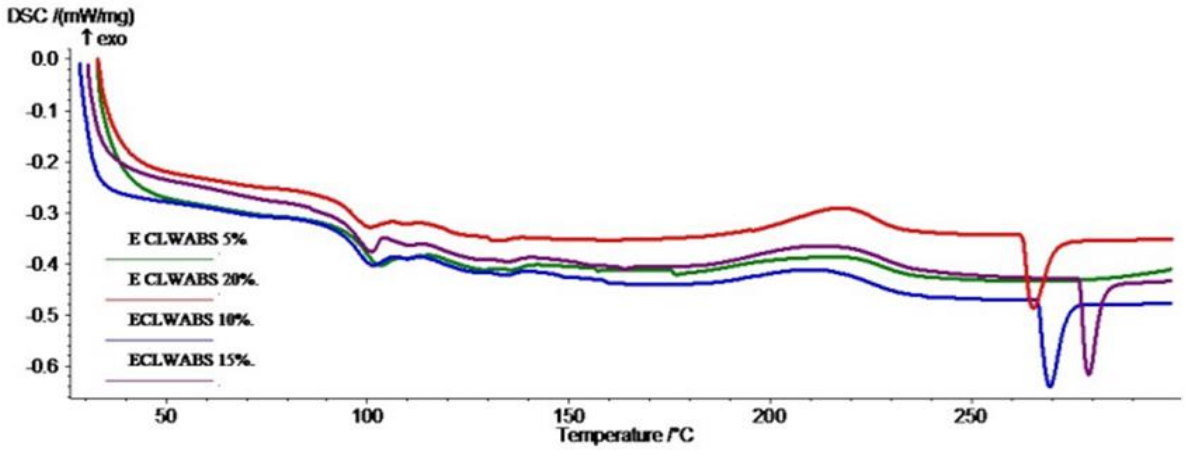

Fig. 9. DSC thermograms of epoxy-coated chrome-tanned leather wastes (ECLWABS) composites at 5 -20 wt% filler loadings.

The epoxy-coated ECLWABS composites exhibited lower Tg values compared to both neat ABS and uncoated composites, indicating ductility over a wider temperature range. This suggests that the epoxy-coated composites would be suitable for applications requiring high impact toughness, especially at temperatures above 75.8°C and below 256°C. In contrast, uncoated composites displayed limited ductility over a narrower temperature range and would not be suitable for robust applications in the same temperature range. This made them suitable for applications requiring high impact toughness. The interplay between fibers and the matrix was examined using scanning electron microscopy (SEM), which revealed cohesive failure in epoxy-coated composites due to strong interfacial bonding.

The study demonstrated that epoxy-coated leather waste fibers can improve the mechanical and thermal properties of ABS composites, making them suitable for various applications [13].

2.5 Leather boards from buffing dust.

The aim of this project is to create cost-effective composite materials using leather waste, with applications in footwear, leather goods, household interiors, and more. Specifically, the study focuses on utilizing leather buffing dust (BD), a solid waste product from the leather industry, for this purpose. The composite materials are developed in the form of boards, and the key binder used in this process is natural rubber latex (NRL). This approach not only contributes to efficient waste utilization but also helps in preventing environmental pollution associated with leather waste disposal. Different concentrations of NRL were used to find out the optimum concentration which gave better mechanical properties. The prepared leather boards were characterized using Fourier transform infrared spectroscopy, thermo gravimetric analysis and scanning electron microscopy. Leather boards prepared using 400 g of BD: 450 mL of NRL possessed better mechanical properties viz. tensile strength, elongation at break (%), flexural strength, tearing strength, etc.

In this study, leather boards (LBs) were fabricated using leather buffing waste and natural rubber latex (NRL) as a binder. The process involved mixing buffing dust with water and various concentrations of NRL, along with ethylene glycol and acid adjustments to create a slurry. This mixture was poured into steel plates, pressed to remove excess water, and then dried and further pressed at a controlled temperature. Physical characterizations of the LBs included Fourier transform infrared (FTIR) measurements to analyze functional groups, thermo gravimetric analysis (TGA) to assess thermal stability, and scanning electron microscopy (SEM) to examine surface morphology. FTIR revealed various chemical bonds present, while TGA showed weight loss patterns during heating, indicating thermal properties. SEM images depicted the dispersion of buffing dust in the NRL matrix.

The mechanical properties of LBs were evaluated, including tensile strength, elongation at break, tearing strength, and flexing endurance. These properties improved with increasing NRL concentration, indicating that NRL contributed to the strength and elasticity of the LBs. Water absorption and desorption properties were also examined, with decreased water absorption and increased water desorption being favorable for applications in footwear and leather goods.

The study also assessed the content of chromium (III) and chromium (VI) in both buffing dust and LBs. The results showed a reduction in the concentration of Cr3? in LBs compared to buffing dust, and Cr6? was undetectable in LBs. Additionally, LBs were subjected to a biodegradation study using collagenase enzyme. The results indicated a biodegradation extent of approximately 5%, suggesting that the LBs were susceptible to enzymatic degradation. The study demonstrates the potential of utilizing leather buffing waste and NRL to produce composite leather boards with improved mechanical properties and reduced environmental impact, including lower chromium content [14].

2.6 Polylactic Acid (PLA) Biocomposites Filled with Waste Leather Buff (WLB)

The This study focuses on addressing the environmental issues caused by the disposal of leather waste generated from tanning industries. The objective is to develop eco-biocomposites by incorporating waste leather buff (WLB) as a filler into a Polylactic acid (PLA) matrix, with the aim of reducing environmental problems and offering a sustainable solution.

The process involves the preparation of WLB/PLA composites by using a twin-screw micro extruder, with varying WLB content ranging from 2% to 30% by weight. Several characterization techniques were employed to assess the properties of these composites. Key findings and observations from this study include,

- Tensile Properties: The addition of WLB to the PLA matrix resulted in an improvement in the tensile properties of the composites. This suggests that WLB enhances the strength and mechanical performance of the materials.

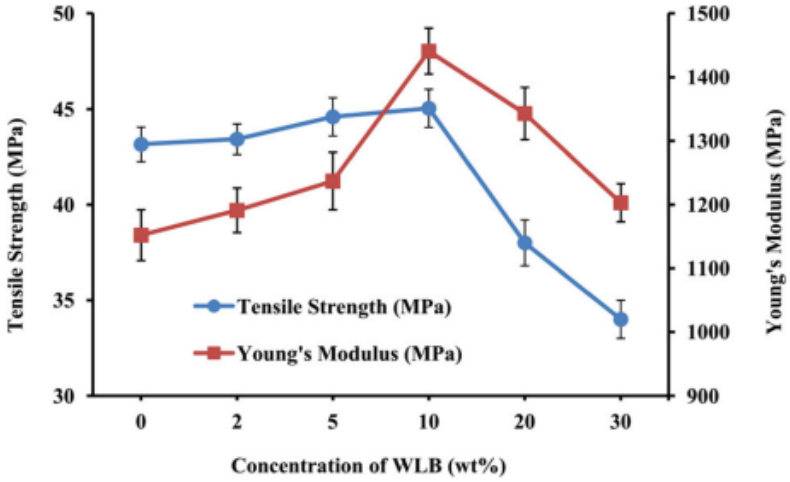

Fig. 10. The effect of WLB content on the tensile strength and young's modulus of WLB/PLA composites.

- Percentage Crystallinity: An interesting observation was the reduction in the percentage crystallinity of the PLA matrix with an increase in the WLB content. This indicates that WLB has an influence on the crystalline structure of the composite.
- Interfacial Adhesion and Dispersion: The study investigated the effect of WLB on the interfacial adhesion and dispersion within the WLB/PLA composites using scanning electron microscopy (SEM). This helps understand how well the filler is integrated into the matrix and the quality of the composite structure.
- Wettability and Water Absorption: Contact angle and water absorption studies were conducted to assess the wettability of the composites. The results indicated an increase in water absorption with higher WLB loading. This could have implications for the composite's performance in wet or humid conditions.

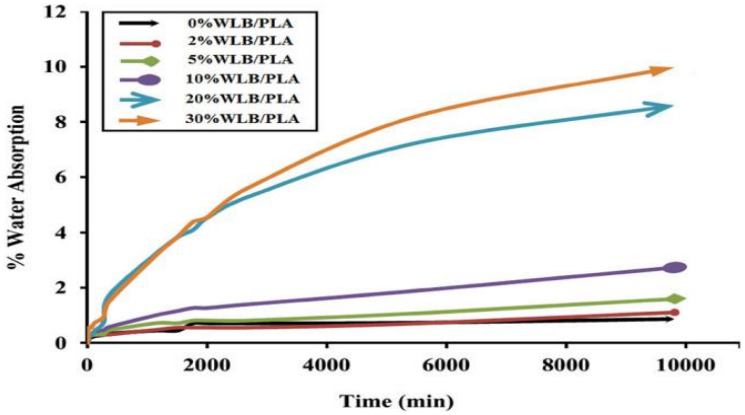

Fig. 11. Water absorption behavior of the PLA and WLB/PLA composites at various WLB concentrations.

The study suggests that WLB/PLA composites have the potential to be used in the development of low-cost and eco-friendly materials for various applications. By repurposing leather waste into useful composites, this contributes to sustainable solutions and environmental conservation [15].

2.7 Development of a flexible composite from leather industry waste and evaluation of their physicochemical properties.

Worldwide leather industry is known to cause high degree of pollution such as soil and water contamination. Dyed trimming, a leather industry waste, is often dumped near the industrial site and is used for land filling. Recycling of such industrial wastes for making useful products by substituting leather has been investigated and reported here. Flexible composite sheets were made from dyed trimmings only and also in combination with natural fibres in various blend ratios. Wastes from jute and cotton were used as sources of natural fibres. In here, composite sheets were developed using a blend of dyed trimmings and natural fibers, with the optimal blend ratio being 50:50. The composite sheets were subjected to various tests following American Society for Testing and Materials (ASTM) and Indian Standard methods to determine their mechanical and physical properties, including ultimate tensile strength, elongation, double fold resistance, bursting strength, density, and water and oil absorption characteristics. The materials used, including the dyed trimmings, jute, and cotton fibers, were analyzed using Fourier-transform infrared spectroscopy (FTIR), thermogravimetric analysis (TGA), (The study examined the thermal properties of waste cotton and jute fibers, dyed trimmings from the leather industry, and composite sheets produced from these materials. Thermogravimetric analysis (TGA) revealed weight loss patterns in three stages for these samples: the first stage (35–200°C) involved the evaporation of absorbed water and crystal water molecules, the second stage (200–400°C) corresponded to the degradation of polymers like hemicelluloses and cellulose in fibers, and the third stage (400–700°C) involved carbonization. Interestingly, the composite sheets displayed enhanced thermal stability in the transition temperature range of 200–400°C compared to individual fibers, indicating interactions between the cellulose in waste cotton and jute fibers and the proteins in dyed trimmings. This interaction contributed to increased thermal stability in the composite sheets, making them potentially valuable materials with improved properties compared to the individual components.)

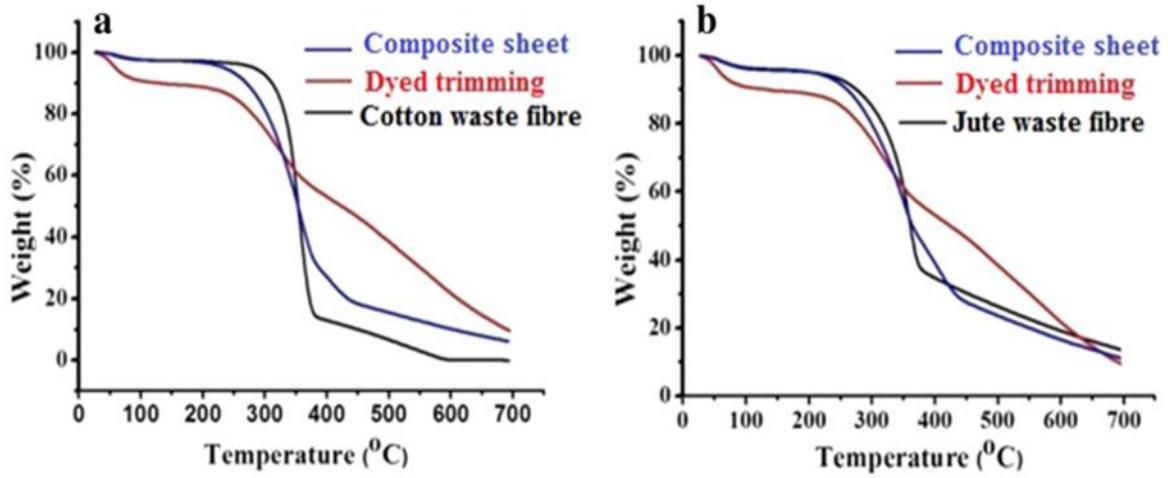

Fig. 12. TGA spectra of a cotton waste, dyed trimming and composite sheets, b jute waste, dyed trimming and composite sheets.

scanning electron microscopy (SEM), and energy-dispersive X-ray analysis. Notably, the composite sheets exhibited superior tensile strength and breaking loads compared to leather, owing to the significant enhancement of mechanical strength and thermal properties due to the inclusion of natural fibers.

The study utilized scanning electron microscopy (SEM) to investigate the surface morphologies of various

materials, including dyed trimming, cotton fibers, jute fibers, and composite sheets made from these components. Dyed trimming exhibited two types of collagen fibers, one longer and larger in diameter, and another narrower and smaller, often displaying longitudinal cracks on the surface. Cotton and jute fibers were continuous, long, and thin, forming strong networks without observable pores or cracks. Composite sheets made from jute fibers and dyed trimming displayed a network of larger-diameter jute fibers embedded with collagen fibers, indicating an interaction between natural and collagen fibers. A similar network was observed in composites comprising dyed trimming and cotton waste fibers. These findings highlighted differences in fiber characteristics among natural sources, potentially influencing mechanical properties and composite behavior. Surface plot diagrams further illustrated these variations, with long-wide and long-narrow fibers randomly distributed in both fibers and composites.

The study investigated the physical strength properties of various materials, including dyed trimming, cotton waste fibers, jute waste fibers, and composite sheets made from these components. Dyed trimming exhibited a lower ultimate tensile strength (UTS) of 65.07 MPa compared to natural fibers, with jute waste fibers at 253.78 MPa and cotton waste fibers at 240.02 MPa. The elongation values for jute and cotton waste fibers were 13.89% and 13.33%, respectively, while dyed trimming displayed a higher elongation of 32.14%, attributed to its collagen content. The breaking load values for all three materials fell within the range of 3075 to 3120 N, indicating their suitability for composite production.

The study further explored the physico-chemical properties of composite sheets fabricated from dyed trimming alone and a combination of jute and cotton waste fibers at different ratios. These composite sheets exhibited an increase in density with rising natural fiber content but still maintained a relatively low density. The tensile strength of the composite sheets improved significantly compared to dyed trimming alone, with values of 54.25 MPa and 52.67 MPa for dyed trimming/cotton fibers and dyed trimming/jute fibers, respectively. Moreover, the use of latex in the composite preparation contributed to enhancing physical strength properties. Additionally, properties like elongation, breaking load, folding endurance, and bursting strength were optimized at a 50:50 blend ratio, ensuring better flexibility and physical strength in the composite sheets. This research underscores the potential of these composite materials for various applications, combining the strength of natural fibers with collagen-rich waste from the leather industry.

Table. 4: Mechanical strength properties of dyed trimmings, jute waste and cotton waste

Sample	UTS (MPa)	Cross-sectional area (mm^2)	Elongation (%)	Breaking load in tensile test (N)
Dyed trimmings waste	65.07	37.55	32.14	3120
Jute waste	253.78	37.18	13.89	3115
Cotton waste	240.02	12.80	13.33	3075

The water and oil absorption properties of composite sheets made from a 50:50 blend of dyed trimmings and cotton wastes were found to be notably low compared to other blend ratios. When soaked for 24 and 72 hours in water, these composite sheets exhibited water absorption capacities of 16.87% and 35.40%, respectively, which were the lowest among all the blend ratios tested. Similarly, the oil absorption values for these composites were 22.50% at low temperature (20–30°C) and 33.38% at high temperature (150 ± 2°C), again ranking as the least absorbent compared to other ratios. These absorption characteristics align with the specifications for cellulose-based products (ASTM F 104 F336486E86M3). The latex treatment, combined with hot pressing during the composite sheet production, played a crucial role in reducing their hygroscopicity and enhancing resistance to oil absorption (Srail and Burroway, 1993). This makes the

composite sheets more suitable for various applications where resistance to moisture and oils is required. These flexible and robust composite sheets have the potential to serve as eco-friendly substitutes for leather in the production of various apparel and goods, offering a sustainable solution while addressing environmental concerns related to leather waste [16].

2.8 Utilization of chrome-tanned leather wastes in natural rubber and styrene-butadiene rubber blends

In this study, various rubber compounds were prepared by incorporating chrome-tanned leather (CTL) shavings into natural rubber (NR), styrene-butadiene rubber (SBR), and NR/SBR blends. The CTL particles were analyzed for particle size distribution, and different mesh sizes were used to determine their fractions. The compounds were then subjected to a series of tests to evaluate their rheological properties, curing behavior, thermal properties, and physico-mechanical properties. The results showed that the incorporation of CTL had a significant impact on the properties of the rubber compounds.

One notable effect of CTL incorporation was a decrease in tensile strength for NR vulcanizates due to the independent tensile action of CTL in the rubber matrix. However, there was almost no change in tensile strength for SBR and NR/SBR vulcanizates, indicating better compatibility of SBR with CTL. Tear strength was significantly enhanced with increasing CTL content in all vulcanizates, making it a potentially important additive for improving tear resistance in rubber products. Thermal aging tests revealed that CTL incorporation could enhance the retention of tensile strength after aging, particularly for NR vulcanizates, where the oxidative inhibition effect of reactive groups on collagen played a role.

The morphological analysis through SEM images showed a tortuous fracture pathway in CTL-containing vulcanizates, explaining the improved tear strength. Additionally, interactions between SBR and CTL resulted in better compatibility, contributing to stable tensile strength values. In NR/SBR blends, both NR and SBR exhibited their interactions with CTL, leading to variable properties. Overall, this study highlights the potential of CTL as an additive in rubber formulations, with its effects varying depending on the rubber type and blend composition, offering insights for applications in the rubber industry [17].

3 Conclusion

The utilization of eco-friendly recycling methods for finished leather waste offers promising solutions to address the environmental challenges posed by the leather industry. Various innovative approaches have been explored, including the development of composite materials such as NR/CB/Leather composites, leather waste/thermoplastic polyurethanes composites, and leather waste-ABS composites, which not only help in waste reduction but also improve material properties for diverse applications. Additionally, the production of leather boards from buffing dust and the incorporation of waste leather buff in Polylactic Acid (PLA) biocomposites demonstrate sustainable practices in minimizing waste. Furthermore, the utilization of chrome-tanned leather waste in rubber blends showcases the potential for reducing environmental impact while creating valuable materials. These eco-friendly recycling methods underscore the importance of sustainable practices within the leather industry, contributing to a more environmentally conscious and resource-efficient future.

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