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Impact of polyvinyl alcohol for bio-adhesives preparation from tannery solid waste and its application in leather products industry

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Abstract

In this study an attempt has been undertaken to utilize the solid wastes generated by the leather industry, particularly raw trimmings, for making bio-adhesive in a cost effective and sustainable way. To enhance the adhesion properties of prepared bio-adhesive, polyvinyl alcohol (PVA) with different ratios were incorporated. Here raw trimmings was hydrolyzed using calcium oxide (CaO) and yielded maximum gelatin of 38.67% at 75°C and 4.5 hrs. The properties of the prepared adhesives were assessed through the various parameters such as viscosity, ash content, pH, density, moisture content, shear strength and peel strength. Considering shear and peel strength test, bio-adhesive containing Gelatin-PVA ratio of 1:4 have shown characteristics features that can be used as temporary adhesive in different stages of leather products preparations. This ratio almost fulfill the standard requirement.

Keywords: Bio-adhesive; Gelatin; PVA; Raw trimmings; Solid waste

Introduction

Recently in Bangladesh, due to significant development, growth, and export potential, leather industry has been designated as a priority sector. Since the industry began to expand in the 1970s, it is counted as one of the ancient industries in Bangladesh. After ready-made garment, it is the second largest export-oriented sector that meets up about 10% of global leather requirements. The industry has experienced gradually growth, propelled by abundance of indigenous raw materials, cost-effective labor, and comprehensive facilities that span the entire supply chain-from the procurement of hides/skins to the leather processing used in production of footwear and leather goods (Islam *et al.* 2018; Mollik, 2022). In Bangladesh, about 56% of the raw materials derive from cow hides, 30% from goat skins and the remaining from buffalo hides (Paul *et al.* 2013). With the increasing population day by day, the demand for leather goods and footwear also increases. Bangladeshi leather is well recognized throughout the world for its premium quality leather, consistent fiber structure, silky feel and natural texture (Khan, 2016). Converting hides/skins to leather involves a complex process comprising three main operations: pre-tanning, tanning and post-tanning (Jayakumar *et al.* 2016). This process requiring numerous chemicals, salts, and other supplementary ingredient. To conserve hides and skins commercial salt is needed and some toxic chemicals like ammonium salts, chromium salts, sulfuric acid, ammonium sulfide and organic tanning agents are required for processing of the hides and skins (Alam *et al.* 2020).

The alarming issue is enormous amount of solid, liquid, and gaseous wastes are released directly from the industry into the environment with or without treatment shown in Fig.1. Globally, the tanning industry generates approximately 6 million tons of solid waste (Li *et al.* 2019),

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and for every ton of raw hides and skins processed, around 200 kg of dry leather and 250 kg of solid tanned waste are produced, emphasizing the significant environmental impact of leather production. Additionally, 100 kg of wastewater and 350 kg of non-tanned waste are produced (Shaibur, 2023). The main ingredients of solid waste are fleshing 50-60%, chrome shaving, chrome splits, buffing dust 35-40%, hide and skin trimmings 5-7%, hair 2-5%. From processing of hides and skins, solid waste constituents pre-tanning 80%, tanning 19% and finishing 1% (Saha and Azam, 2021). Trimming is the process of cutting and eliminating additional or undesirable pieces from raw hides and skins in order to create a particular shape during the leather-making process. As they don't contain any hazardous chemicals, they are safe to use. These may be available in the raw, salted, limed, wet blue, finished leather from various stages of unit operation in leather production. For the manufacturing of gelatin, all forms of trimmings are applicable (Shakil *et al*. 2019) which contains protein and are less contaminated by chemicals than trimmings of tanned and finished leather as it generated before tanning stages. As a result, it is more environment friendly and sustainable to prepare valuable product from these solid wastes.

Fig. 1. Raw Trimmings discarded in yard of Savar Tannery Estate without treatment (Authors)

The gelatin that is extracted from raw trimmings of hides and skins can be a potential source of making adhesive, which is a value-added product (Hubner *et al.* 2021). For the preparation of gelatin, pretreatment and curing process are the initial steps. To improve the availability of gelatin to the hydrolytic environment, trimmings are pretreated by being soaked in either acid or alkali. Trimming needs to be treated to make the protein soluble because it is water-insoluble in its native state. There are both non-polar and charged acidic and basic side chains in the triple-helical amino acid sequence of collagen molecule. Trimming must first be subjected to an acidic or alkaline pretreatment in order to interrupt the intra- and intermolecular polypeptide linkages before being extracted. Pretreatment techniques include acidic, alkaline, and enzymatic processes (Negash *et al.* 2020).

An adhesive is a material that clings to an object's surface, resulting two surfaces to connect. Adherends refer to the solid components or substrates, whereas adhesive joints and adhesive bonds refer to the linking or compilation produced by the adhesives. The process known as adhesion is what enables the adhesive to transfer a load from the adherend to the adhesive junction (Saikumar, 2002). An adhesive needs three key characteristics in order to function well. Firstly, it must be capable of moistening or wetting the substrate. A liquids capacity to remain in touch with a solid surface is known as wetting. Secondly, it must become stronger after appliance. Thirdly, it must be able to transfer load between the two surfaces or substrates being attached. The mechanism of adhesion is often used to classify adhesives. These are divided into reactive and non-reactive adhesives, depending on whether a chemical reaction occurs to cause the adhesive to solidify.

The raw material may also be arranged according to its origin; natural or synthetic. Adhesives that are derived from organic or natural sources, such as plant-based materials (starch) or animal-based materials (gelatin), are known as natural or bio-adhesives. Bio-adhesives are considered more environment friendly than synthetic adhesives that are originated from petrochemicals. Bio-adhesives have been used for centuries in various applications and industries. Since at least 200 years, simple gelatin and water mixers have been employed in book binding along with thousands of years of woodworking. Modern animal adhesives also contain performance enhancers like plasticizers, sugars, salts, surfactants, antifoams and biocides in addition to gelatin and water (Miu and Niculescu, 2022). The most significant industrial uses of bio-adhesive are presented in Fig. 2. Animal sourced bio-adhesives include albumin, animal glue, casein, shellac, beewax; in the same way gum arabic, tragacanth, colophony is vegetable; soyabean, starch, dextrin are proteins and carbohydrates; carnauba wax, different oils are waxes and oils; silicates, magnesia, phosphates, sulphur, paraffin, amber are minerals; asphalt is bitumen (Dinte and Sylvester, 2018).

The size of the world market for adhesives and sealants, estimated at USD 67.48 billion in 2022 and from 2023 to

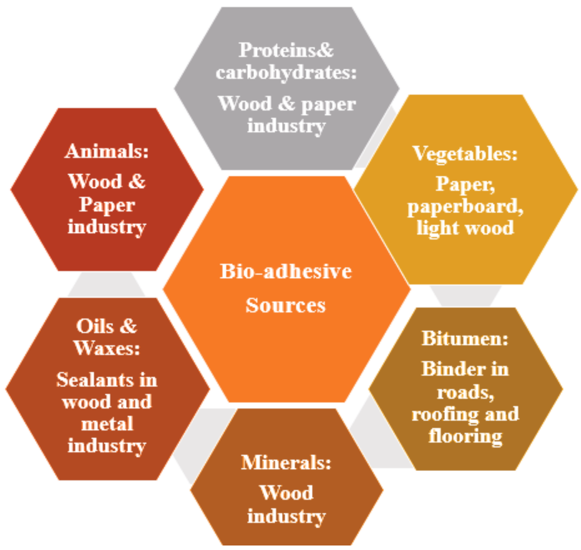

Fig. 2. Industrial uses of common bio-adhesives (Dinte and Sylvester, 2018)

2030, it is anticipated to grow at a compound annual growth rate (CAGR) of 6.0% (Grand View Research, 2023). According to Volza's (USA based market research Company) data on Bangladesh imports up to May 2023, 3.5 M. Ton adhesives were imported. The majority of Bangladesh's adhesive imports come from Hong Kong, China, and India (Volza, 2023). Adhesives plays a crucial role in the leather industry, especially for the production of leather goods. In footwear industry, adhesives are used for manufacturing different varieties of shoes. They are used to bond various components of the shoe together, such as upper, lining, insole, outsole, and other joining. In the leather goods industry, it is widely used in temporary bonding of various section of goods.

Usually, the extracted gelatin has low molecular weight with abundant hydrophilic groups. Therefore, directly

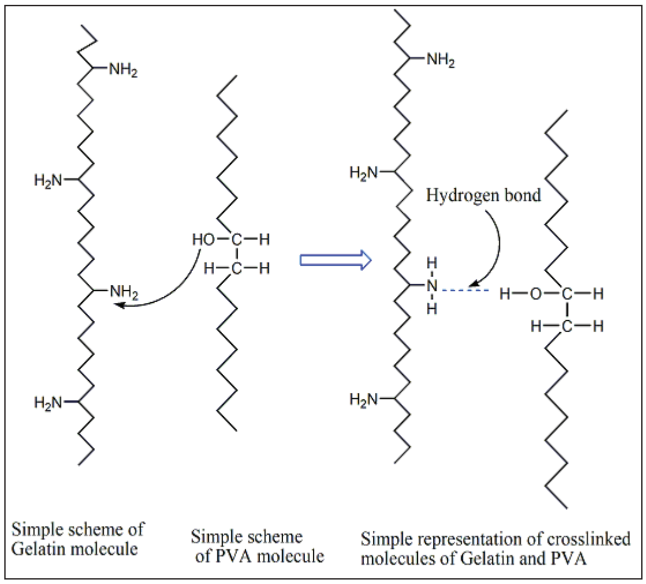

Fig. 3. Probable crosslinking of Gelatin-PVA (Hubner *et al.* 2021)

applying these hydrolyzed adhesives will have issues with their weak adhesive strength. By raising their molecular weight through crosslinking as Fig. 3, hydrolyzed adhesive must be improved for its sticky capabilities (Zhou *et al*. 2017). Some studies are performed earlier with adhesive preparation from leather shaving dust (Shaikh *et al*. 2017; Gebremariam *et al*. 2023), hide trimming waste (Negash *et al*. 2020), cattle bones waste (Gunorubon and Misel, 2014) and hide glue (Miu and Niculescu, 2022). In the present study, an attempt has been made to prepare bio-adhesive from raw trimmings of hide and skin using polyvinyl alcohol (PVA) - a synthetic water-soluble polymer to increase its adhesion property. Here, gelatin extraction method from raw trimmings was different varying extraction time and temperature and application of prepared bio-adhesive was examined in making bonding of leather products. With proper implementation of the present work, adhesive production from the tannery sectors as a value-added product can influence the revenue as well as can minimize environmental pollution load from leather solid waste.

Materials and methods

Materials and chemicals

The raw material for the present study was raw trimmings of hide and skin was collected from a tannery state of Savar, Bangladesh. The analytical-grade chemicals are utilized for the experiments were calcium oxide, hydrochloric acid (35%), polyvinyl alcohol (98-99%), glycerol, lemon grass oil, fungicide, bactericide, distilled water.

Treatment and preparation of raw materials

300 g of raw hides and skin was washed four times with tap water in a beaker. The washed trimmings were then soaked in 600 mL of 4% limed water (CaO) for a period of seven days and the trimmings were washed again with tap water, and the hair was removed using a knife. Trimmed material was cut into small pieces measuring 10 mm x 10 mm and neutralized with 200 mL of 35% hydrochloric acid, pH level was adjusted at 6. Then the trimmed materials were transferred in a beaker with magnetic stirrer for 3-4.5 hrs at 75°C and 250 rpm. After complete hydrolysis, the non-collagen part was discarded from liquor solution using nylon cloth. The liquor solution was boiled at 70°C in a rotary evaporator (DLAB RE100-Pro) to extract the collagen. After that, the remaining excess water was evaporated using a magnetic stirrer. The resulting hydrolysate was collected and stored in a refrigerator at 7°C. After the characterization of raw trimmings, pH, Ash content, Moisture, and Nitrogen content were found 6.41, 12.5%, 23.94% and 21.47% respectively has shown in Table I.

Table I. Characteristics of raw trimmings

Parameters	Values	Method
Ash content (%)	12.5	SLC 04
Moisture content (%)	23.94	SLC 113
pH	6.41	SLC 120
Nitrogen content (%)	21.47	SLC 07

Production of bio-adhesive

In the second stage, the prepared hydrolysates were heated in a water bath for a minimum of 2-3 hrs to remove any remaining excess water. Approximately 10 g of the extracted hydrolysates were placed in a beaker and stirred using a magnetic bar on a hot plate until the gelatin-like protein transformed into a liquid like water. The temperature was maintained at 60-75°C throughout the entire process. Polyvinyl alcohol was added to the extracted samples in various ratios, such as 1:1, 1:2, 1:3, 1:4 and 1:5. Prior to adding the polyvinyl alcohol, it was melted by heating in an oven with distilled water (1:3) at 200°C. Glycerol was added during the operation to prevent the mixture from burning. Furthermore, 3-4 drops of lemon grass oil were added to the mixture and rotated for 1-1.30 hrs to eliminate any unpleasant odor. To protect the adhesive from bacterial and fungal attacks, a fungicide was added to the mixture, allowing 30 minutes between each addition. Finally, the adhesives were collected and stored for further testing. The procedure for the preparation of bio-adhesive from raw trimmings shown in Fig. 4.

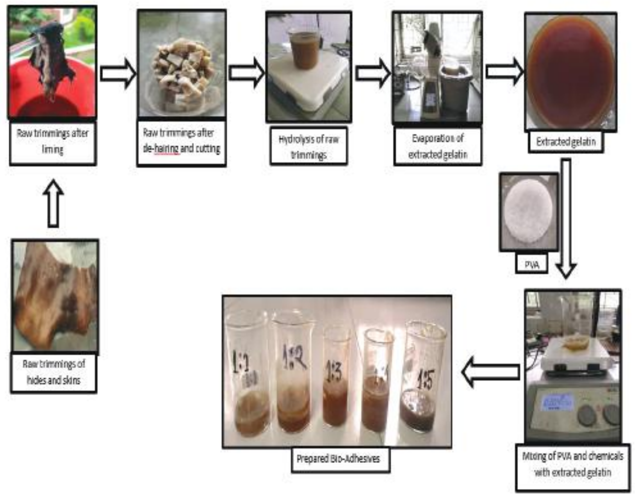

Fig. 4. Various steps for preparation of bio-adhesive from raw trimmings

Effect of temperature and time on yield of gelatin

Several factors including temperature and time influences the yield of gelatin from protein extraction. Collagen is a protein found in connective tissues of animals primarily skins and bones. The process of converting collagen into gelatin involves breaking down the collagen fibers and extracting the gelatinous material. At higher temperature above 90°C, denaturation of protein occurs. The time of exposure to temperature is also important. Longer extraction times allow for more breakdown of collagen into gelatin. But excessively long extraction time can lead to decrease in gel strength. So, it is essential to make a balance between temperature and time to achieve the maximum gelatin yield and quality. In the present study, for extraction of gelatin from raw trimming of hide and skin the effect of temperature and extraction time has been studied under different conditions 60°C, 65°C, 70°C, 75°C and 3 h, 3.5 h, 4 h, 4.5 h accordingly.

The gelatin yield was calculated as follows:

$$\text{Gelatin Yield (\%)} = \frac{\textit{Dry Weight of Gelatin}}{\textit{Initial Weight of Raw trimmings}} \text{ X } 100$$

Physicochemical analysis of prepared bio-adhesive

Moisture content

Moisture content refers to the amount of moisture or water present in a substance or material, typically expressed as a percentage of the material's total weight. The properties and performance of adhesive are significantly affected by this parameter. Water-based adhesives contain water as a primary solvent. Too much moisture can dilute the adhesive and affect its bonding properties, while too little moisture can result in a thick, unworkable adhesive. In present study, oven- drying method was used for determination of moisture content. 10 g of sample mass was weighed (m_1) in a balance (RADWAG AS220.R2) before drying in an oven (Memmert, max 300°C) at 110°C for 16 h. The mass of sample was taken after drying (m_2). The following formula was used to calculate moisture content.

$$\text{Moisture content (\%)} = \frac{\text{Weight of sample before drying-Weight of sample after drying}}{\text{Weight of sample before drying}} \times 100\%$$

$$= \frac{m_1 - m_2}{m_1} \times 100\ \%$$

Ash content

Ash content refers to the amount of inorganic residue left behind when a material is combusted or subjected to high temperatures until it is completely burned or oxidized. It is commonly expressed as a percentage of the materials total weight. For measurement of ash content, assessment of weight loss upon ignition at 600°C for 2 h in an electric muffle furnace (JSMF-30T) was performed. The 10 g of sample was weighted in a balance and was dried in the oven at 110°C for 16 h with the purpose to vaporize the moisture. After that, the remaining sample weight was measured (m_1) and the dry sample was added to the crucible. Finally, the dry sample was ignited in the furnace for 2 h at 600°C. After cooling in a desiccator, the collected ash was measured to determine its weight (m_2).

$$\text{Ash content (\%)} = \frac{\text{Weight of sample after ignition}}{\text{Weight of sample before ignition}} \times 100\%$$

$$= \frac{m_2}{m_1} \times 100\ \%$$

pH value

Quantitative measure of the acidity or basicity of aqueous or other liquid solutions is determined by pH value. pH may impact the adhesive's ability to resist or absorb moisture. A digital pH meter (HI 98107 with pH buffer 7.01) was used to measure pH. The pH meter was inserted into a beaker containing the adhesive sample and the reading was taken.

Viscosity

Viscosity of a fluid can be described as its resistance to flowing or deforming. It is a property that characterizes how easily a fluid can move or be deformed under the influence of an external force, such as gravity or applied shear stress. The property will affect the extent of penetration into substrate. If the viscosity is too low the adhesive may penetrate too far into the substrate. High viscosity may prevent adequate penetration. To evaluate the quality of product, measurement of viscosity of prepared sample is necessary. In the beginning, 50 mL of a 12.5% adhesive solution were prepared and heated to a temperature of 60°C. For the final measurement, the sample was tested using a viscometer.

Density

Density is a fundamental physical property that measures how much mass is contained in a given volume of a substance. The density of the adhesive was determined by taking the weight of a known volume of the prepared adhesive in a density bottle (Pycnometer) using an analytical balance.

$$\text{Density of adhesive} = \frac{\text{Mass of adhesive obtained}}{\text{Volume of adhesive obtained}}$$

Shear strength

Shear strength is a measure of the maximum resistance of a material to deformation due to applied shear stress. Shear stress is the tension that results from applying forces parallel to a surface, which allows one material layer to move or distort in relation to a neighboring layer.

$$\text{Shear strength} = \frac{F}{A} \left(\frac{N}{mm^2}\right)$$

Where F is the required force to shear the bonded material and A is the cross section area of the bonded material.

Here the test of shear strength was performed in a Universal Testing Machine (SATRA STM 566) using method (ASTM D5868, 2014) with shear strength rate 13 mm/min. Each finished leather was cut into 100× 25 mm in which overlap width was 25 mm Fig. 5.

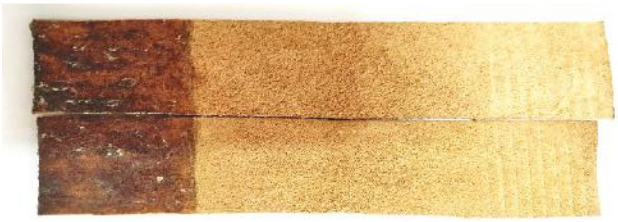

Fig. 5. Shear strength test for prepared bio-adhesives

Peel strength

Peel strength testing is often used to assess the quality and durability of adhesive bonds and other bonded materials. It can help to determine whether an adhesive or bonding method is suitable for a particular application. Peel strength is the amount of force needed to separate two surfaces or materials that are bonded together. It is typically expressed in units of force per unit width of the prepared adhesive.

$$\text{Peel strength} = \frac{F}{W} \left(\frac{N}{mm}\right)$$

Where, F is the force required to detach the joined materials and W is the bonded width.

In the present study, peel strength test was performed in a Universal Testing Machine (SATRA STM 566) using method (SATRA TM 401, 2001) with peel strength rate 50 mm/min. Each finished leather was cut into 150×30 mm in which overlap width was 100 mm and after joining with prepared adhesive it was kept at room temperature for seventy- two hrs Fig. 6.

Fig. 6. Peel strength test for prepared bio –adhesives

Results and discussion

Effect of temperature and time on yield of gelatin

The production of gelatin gradually increases with rising temperature and passage of time along with Fig. 7. Due to some un-extracted gelatin, the yield of gelatin was lowest at 60°C. The yield of gelatin is increased in line with the lengthening of the extraction process and at 75°C and 4.5 hrs, the maximum gelatin production (38.67%) was attained. However, the denaturation of proteins at 80°C resulted in a reduction in the gelatin production. The comparison of extraction method and yield with previous works are showed in the Table II.

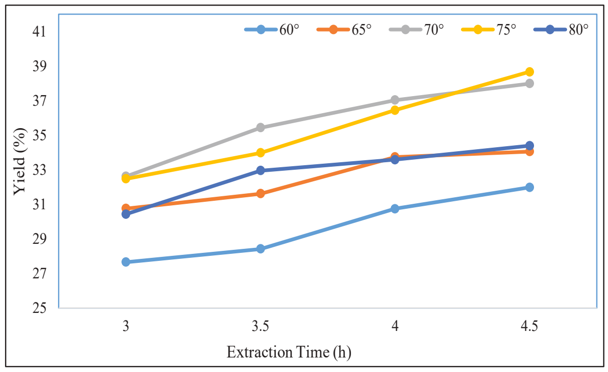

Fig 7. Effect of time on gelatin yield (%) at different temperature

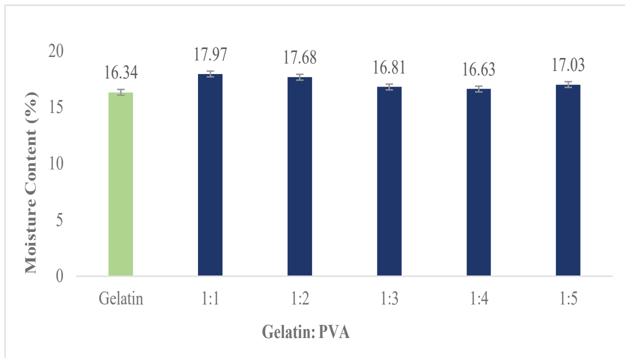

Fig. 8. Effect of moisture content on Gelatin and PVA ratios

Physicochemical analysis of prepared bio-adhesives

Moisture content

The lower value of the moisture content is better for the adhesive due to some specific reasons such as excessive moisture can weaken the bond strength and provides favorable environment for mold and fungal growth in adhesive. It also interferes with curing and setting time of adhesion. From the Fig. 8, it has been observed that with increasing ratios of PVA with gelatin, the moisture content decreases up to 1:4 and then increases from the prepared bio-adhesives with Gelatin and PVA, ratios of 1:4 (16.63%) has moisture content value analogous with the value of extracted gelatin (16.34%)

Table II. Comparison of yield with previous works

Sources	Extraction	Yield (%)	Ref.
Chrome-tanned wet blue shaving dust	MgO, 75°C; trypsin	-	Gebremariam *et al.* 2023
Chrome shaving leather waste	Li_2CO_3; 80°C	36	Taha 2023
Raw trimmings	Water; 85°C	46	Shakil *et al.* 2019
Hide trimmings waste	NaOH; 65°C	32	Negash G *et al.* 2020
Raw trimmings of hides and skins	CaO; 75°C	38.67	This study

from raw trimming of hides and skins.

Ash content

Lower value of ash content is desirable for a good adhesive to be environment friendly as it indicates less inorganic residues. Higher ash content value of adhesives might be less flammable but it may have an effect on the adhesive strength, particularly if it obstructs the bonding process or prevents a strong bond from forming. The ash content of the prepared bio-adhesive exhibited an increasing trend with the addition of gelatin. According to Fig. 9, the extracted gelatin had an ash content of 1.54%. Consequently, the incorporation of

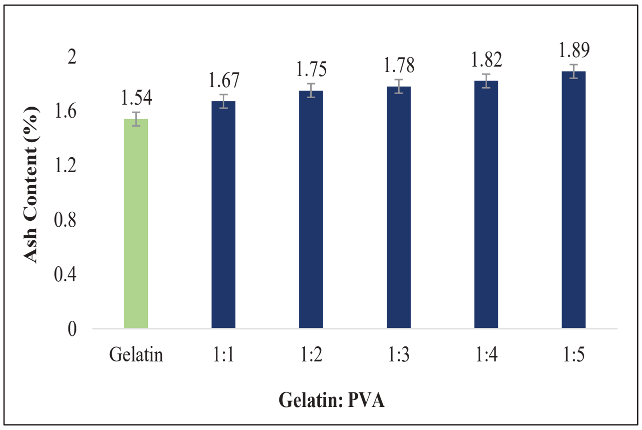

Fig. 9. Effect of ash content on Gelatin and PVA ratios

gelatin into the PVA-assisted gelatin bio-adhesive resulted in an increase in ash content.

pH value

An adhesive's ability can be affected by its pH. Abnormally high or low pH levels can cause chemical deterioration, which can affect the adhesive's overall performance and shelf life. The adhesive's flow properties can be changed by pH changes, which can affect how the adhesive spreads and sticks to surfaces. According to Fig. 10, extracted gelatin is

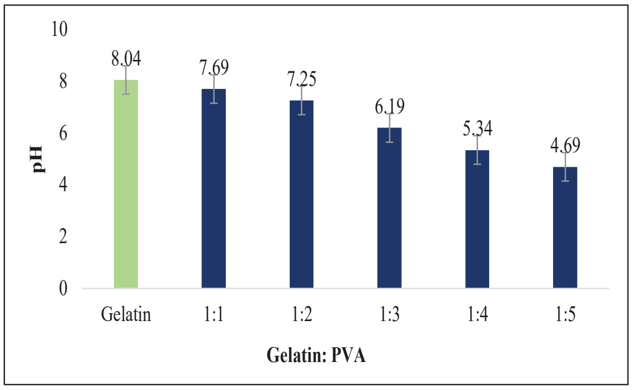

Fig. 10. Effect of pH on Gelatin and PVA ratios

slightly alkaline in nature and PVA is slightly acidic in nature. After the addition of PVA to Gelatin a deceasing pattern alkalinity was exhibited.

Viscosity

Viscosity may influence how long an adhesive takes to cure or set. In general, low-viscosity adhesives are simpler to distribute, apply, and dispense as well as wet surfaces more thoroughly, improving adherence and contact. According to Fig. 11, the viscosity of the prepared bio-adhesive increased

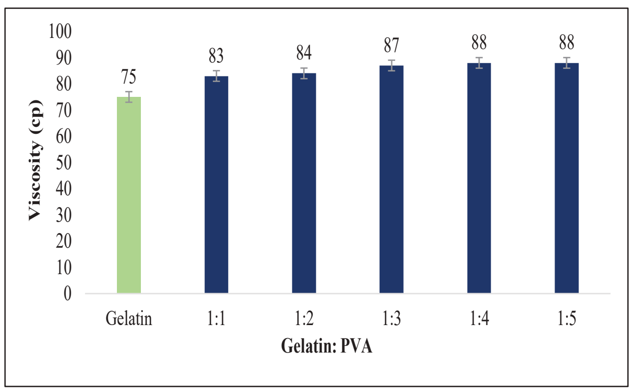

Fig. 11. Effect of viscosity on Gelatin and PVA ratios

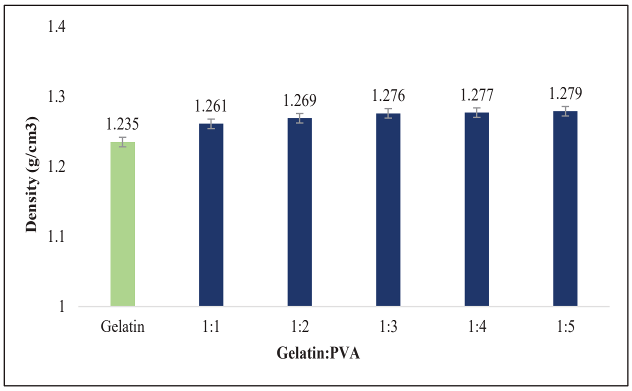

Fig. 12. Effect of density on Gelatin and PVA ratios

with the addition of PVA, reaching its highest values at ratios of Gelatin and PVA 1:4 and 1:5 (88 cp). Gelatin extracted from raw trimmings has lower value of viscosity (75 cp).

Density

The density of the adhesive can influence the thickness of the bond line between the adhered surfaces and its ability to fill gaps and create a uniform bond line thickness. Adhesives with higher density value may provide more coverage for a

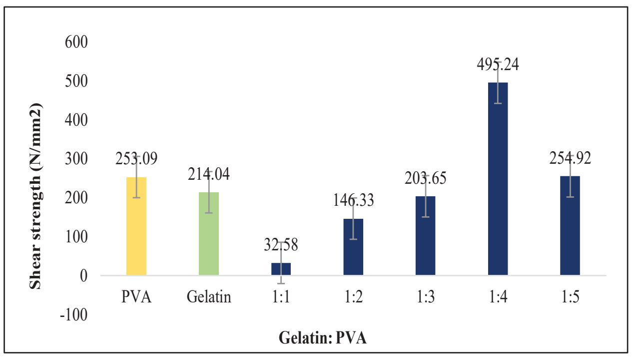

Fig. 13. Shear strength of PVA, Gelatin and prepared bio-adhesives

given mass, effecting the overall cost-effectiveness of the adhesive in a particular application. From Fig. 12, with increasing ratio of PVA to Gelatin the density also increases and reaches maximum at 1:5 (1.279 g /cm^3).

Shear strength

An adhesive's shear strength is a fundamental property that affects the performance, durability and reliability of bonded joints. In many industries, it is considered one of the key parameters in the testing and quality control of adhesive bonds. Higher shear strength is essential for maintaining the integrity of bonded joints under shear loads. According to Fig. 13, the highest shear strength of prepared bio-adhesives was found at Gelatin and PVA ratio of 1:4, representing a remarkable increase of approximately 95% compared to the shear strength of PVA and a significant 131% increase compared to the shear strength of gelatin.

Peel strength

Adhesives that have the suitable peel strength can withstand deformation and movement without weakening the bond. Adhesives with high peel strength resist separation of bonded materials, ensuring a durable and reliable bond. From Fig. 14. it can be said that gelatin as well as Gelatin and PVA

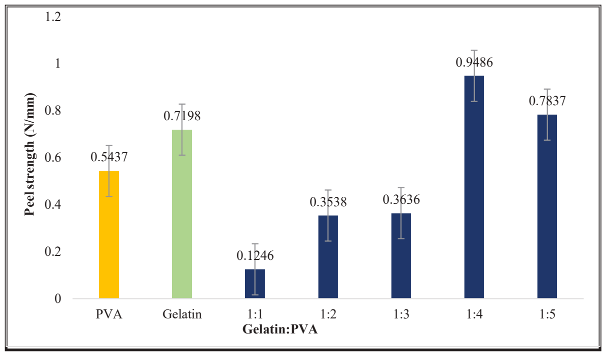

Fig. 14. Peel strength of PVA, Gelatin and prepared bio-adhesives

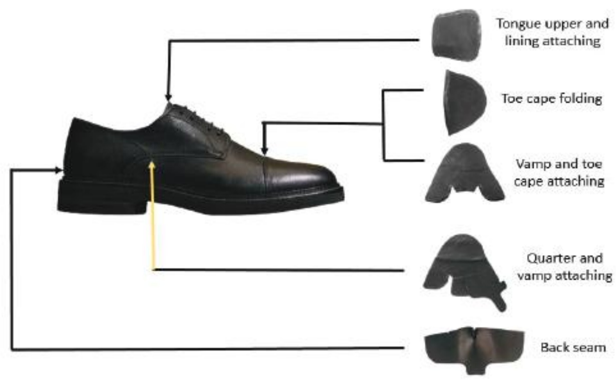

Fig. 15. Temporary adhesive used in different upper parts of footwear

ratio of 1:4 has exhibited higher peel strength 0.7198 N/mm and 0.9486 N/mm respectively. According to standard ISO 20344:2004, the reference values of peel strength for upper/sole adhesion in footwear designed for babies, children, women and men are ≥ 2 N/mm, ≥ 4 N/mm, ≥ 3 N/mm and ≥ 4 N/mm respectively (Paiva *et al*. 2013).

Since the peel strength value is lower than reference values of adhesion upper/soles for shoes the prepared bio-adhesive can not be used for permanent bonding of any substances. The

Table III. Comparative value between prepared bio-adhesive and standard adhesive (Negash *et al.* 2020)

Parameters	Prepared bio-adhesive						Standard	PVA	Others Report
	Gelatin	1:1	1:2	1:3	1:4	1:5			
Viscosity (cp)	75	83	84	87	88	88	80.0	25-32	90
Ash content (%)	1.54	1.67	1.75	1.78	1.82	1.89	2.00	0.7	2.23
pH	8.04	7.69	7.25	6.19	5.34	4.69	6.06	5.0-7.0	5.89
Density (g/cm^3)	1.235	1.261	1.269	1.276	1.277	1.279	1.270	-	1.259
Moisture content (%)	16.34	17.97	17.68	16.81	16.63	17.03	15.0	-	14.6
Shear strength (N/mm^2)	214.04	32.58	146.33	203.65	495.24	254.92	>200	253.09	260
Peel strength (N/mm)	0.7198	0.1246	0.3538	0.3636	0.9486	0.7837	≥3(Women) ≥4 (Men)	0.5437	-

Comparison of physicochemical properties of prepared bio-adhesive and standard value are given in Table III.

Applications

For a variety of purposes, temporary adhesives are frequently used in the production of leather goods and footwear. One benefit of these adhesives is that they provide the ability to disassemble and reposition components without creating a permanent bonding. During footwear manufacturing, it is essential to choose temporary adhesives that are easy to remove, do not damage the leather, do not leave residue after removal and also cost-effective. While the footwear components are assembled together as well as during the insertion of foaming materials, these adhesives can be employed between the upper and lining to temporarily attach in the position depicted in Fig. 15. This ensures accurate alignment and prevents shifting during the sewing process. The sole can be kept in place temporarily with temporary adhesives before being permanently stitched. This allows for adjustment and ensures that the sole is correctly aligned before the final bonding process. These adhesives are engaged to secure the heel in place in the mean time before it is nailed or permanently attached to the sole. These adhesives can also be used on leather goods for applications requiring a temporary bond, such as folding, assembling, inserting reinforcement material, etc.

Conclusion

The main objective of the present study is to find a cost-effective and environment friendly way of utilizing raw trimmings of hides and skins for solid waste management of leather industry. For implementation of this, a research work has been performed to prepare bio-adhesive from extracted gelatin with PVA and examined its applicability in leather products industry. By varying the extraction time and temperature, maximum yield of gelatin (38.67%) was found at 4.5 hrs' extraction at 75°C temperature. The gelatin production method is different from the previously cited work. Considering physicochemical properties of gelatin and five bio-adhesives, Gelatin along with Gelatin and PVA ratio 1:4 performed characteristic properties of adhesive. Due to lack of optimum level of copolymerization mixing of PVA with gelatin, remaining four bio-adhesive has not fulfilled the desired requirements. However, gelatin and Gelatin: PVA (1:4) does not provide strong bonding capabilities but this can be used as low grade adhesive in footwear and leather product industry where permanent bonding is not necessary. Further studies have to be performed to improve the adhesive property for commercial production.

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