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A feasibility study on use of banana fabrics in footwear production as upper material

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The purpose of this research is to evaluate the physical, comfort, structural and thermal properties of banana fabrics for their suitable use with cow nubuck and goat nubuck leather in footwear applications. It is observed that all these fabrics have mechanical properties comparable to those of cow nubuck and goat nubuck leather. The tensile strength of the banana fabric is sufficiently higher than that of cow nubuck and goat nubuck leather. Cow nubuck leather, on the other hand, outperforms all other fabrics in terms of percentage elongation. Scanning electron microscopic examination gives solid proof of the banana fabrics' distinctive fibre pattern in each fibre bundle (yarn) as well as their composition. The banana fabric has greater thermal stability than cow nubuck leather. The results of this investigation indicate that the chosen banana fabrics can be used to create footwear.

Keywords: Banana fibre shoes, Combination products, Cow nubuck leather, Footwear production, Goat nubuck leather, Natural fibres

1 Introduction

On the surface, footwear design does not appear to have changed significantly over the last century. However, the techniques used in shoe fabrication have undergone revolutionary changes[1]. As far back as the origins of the shoe industry, leather has been the primary material used to create footwear, accounting for nearly half of all leather produced today. Moreover, a quarter of the world's population uses leather goods. According to the UN Industrial Development Organization[2], 19 billion pairs of shoes are made each year in the footwear industry globally, which is ranked second in the fashion industry. Shoes that are appropriate for one's professional or personal life are in high demand in today's fast-paced society. Shoe types range from slippers to sneakers to custom-made footwear[3]. An estimated 20 billion square feet of leather is produced annually around the globe. To make one ton of leather, 6.7 tonnes of raw skin, 57,000 litres of water, and 3.35 tonnes of chemicals are needed[4]. Since the dawn of human civilization, the leather industry has been regarded as a traditional manufacturing sector, and many nations still view it as a possible source of export revenue[5]. Hides and skins are tanned and post-tanned to provide a more stable material with improved functional properties[6,7]. Leather is a natural material of protein fibre origin. The skin is made up of a web of randomly linked fibre bundles made up of seemingly interminable fibroblasts[7]. Nubuck leather has packed short strands and is slightly rough on the surface. Nubuck leather is made from the outermost (top-grain) layer of hides and skins. The top layer of grain is stiffer and more flexible than the inner layer. Nubuck leather is regarded as having the optimum breathability and comfort in humid conditions. If necessary, polymers can be included to obtain good physical qualities without sacrificing elasticity and flexibility. A one-sided ultra-fine fibre (grain) nap surface is provided by nubuck leather. When polished, it gives a napped finish. Nubuck is more durable and robust than suede since it is made of high-grain leather. It's also more durable than pixie leather or bonded leather, which does not utilize the leather's top grain. However, because of its rough surface, it is more prone to stains than other leathers. Shoes, jackets, wallets, handbags, suitcases, furniture and a variety of other goods are made of nubuck. Because of its velvety surface, which requires cleaning from time to time, it requires less maintenance than many other types of leather[8]. Leather appearances are usually improved when processed but this process leads to the release of liquid and solid wastes into the environment[9]. Recent

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years have seen a rise in the usage of natural cellulosic fibres in polymer composite production as an alternative to standard fibres, such as glass, carbon, and aramid[10].

Biodiversity has long been a source of nourishment for humans throughout human civilization from food, textiles and fuel for heating and cooking as well as medicines, plants were also instrumental in a variety of other items[11]. An alternative material with potential functional properties to replace leather has recently picked up the interest of researchers. Inorganic and synthetic fibres have some drawbacks, including low biodegradability, abrasion on processing equipment, high cost and density, and safety concerns for the workers who handle and process them. There are many advantages of using natural fibres as a substitute for synthetic fibres, including their low specific weight, low density, high acoustical efficiency and mechanical strength[12–15]. Natural fibres are a low-cost and readily replaceable source of raw materials[16]. They are environment-friendly materials that are easily biodegradable[12,14,15]. As people's concern for the environment has grown, an interest in the natural fibres has also grown up along with the many uses these fibres may serve. As possible reinforcement fibres, natural fibres have long been used in commercial applications[14,15,17].

Tropical regions have a wide variety of fibrous plants, some of which are grown for nutrition, like bananas. The waste product from banana farming is now banana fibre. Banana fibre may therefore, be acquired for industrial use at no extra expense. Banana (*Musa acuminata*) fibres have been used as an alternate fibre reinforcement in composite materials in previous investigations[17–19]. Reinforcement of banana fibres with un-saturated polyester has been commonly reported[20,21].

Aside from its usage as a source of cellulose fibre and structural reinforcement in composites[22], banana fibre has a variety of applications in the textile and handicraft industries, as well as in composite boards and the paper industry[22]. The present study analyses the properties of banana fabrics, and cow and goat nubuck leathers for leather footwear production applications.

2 Materials and Methods

2.1 Materials

Goat nubuck leather of thickness 0.8 mm ±0.2 and cow nubuck leather of thickness 0.8 mm ±0.2 were sourced from M/s Well shine Impex, Ranipet. Two types of banana fabrics (S1 and S2) were sourced from M/s GO Green India Solutions, Chennai and the specification of the procured banana fabrics are given in Table 1.

2.2 Test Methods

2.2.1 Sampling and Conditioning

Before conducting physical testing, leather samples were collected from the designated sampling location and conditioned for 48 h at a standard temperature of 27.2°C and relative humidity of 65.2%. Four samples were taken from both banana fabrics and leather for tests and the mean values and standard error were calculated and reported using statistical analysis. To test the tensile strength, tongue tear strength, stitch tear strength and elongation-at-break of leather, samples were sliced in parallel and perpendicular directions to the backbone. In the case of banana fabric samples cut along the warp, direction was labelled parallel (for comparison with leather samples), while samples cut along the weft direction were labelled perpendicular (for comparison with leather samples)[7,23].

2.2.2 Tensile Property Analysis

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 dumbbell-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 elongation-at-break[7,23].

2.2.3 Stitch Tear Strength Analysis

Using the double hole stitch tear method, the stitch tearing resistance was assessed[24]. 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 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[7,23].

2.2.4 Tongue Tear Strength Analysis

The weight needed to tear a test specimen between two tongues created by splitting the specimen perpendicular to its surface allowed researchers to quantify the specimen's tearing strength[24]. Following the measurement of the specimen's thickness, both of the tongues were put into each jaw of the Universal Testing Machine (M/s Instron Inc., UK) with the inner cut edge aligned with the centre line of the jaws. Jaw separation occurred at a speed of 75 mm/min. The load was measured at the time of the initial tear and given in N/mm[7,23].

2.2.5 FTIR Spectroscopic Analysis

The structural characteristics of samples of banana textiles and leather were assessed using FTIR spectroscopic analysis utilizing an FTIR spectrometer 4200 (USA). The samples were made by grinding pure potassium bromide into a fine powder (KBr). After being crushed in a mechanical die press to create a translucent pellet, this combination was then used to create the transmittance spectrum[7].

2.2.6 SEM Analysis

SEM analysis was carried out to evaluate the structural morphology of banana fabric samples and leathers. For this, samples of size 5×5 mm^2 were cut from both banana fabrics and leathers. Through the use of compressed gas blowing, dirt was eliminated. Double coated adhesive tape was used to secure the samples to a 10mm diameter brass stub specimen. The Phantom (Japan) ion sputter coater was used to apply a thin conductive gold coating to the samples. The materials were investigated under a high vacuum with a Phantom SEM (Japan) at various magnifications[7].

2.2.7 TGA Analysis

A thermo gravimetric analyzer (TA Instruments, V4.4A, USA) was used for TGA analysis. The specimen was balanced on a pan using a high precision balance. The pan was placed in a small electrically heated oven that was monitored and controlled by internal thermocouples. To prevent oxidation and other undesirable processes, nitrogen gas was removed. To assess the properties of the specimen, the temperature was gradually raised at a rate of 20°C/min, and weight was plotted versus temperature[7].

2.2.8 Sole Bond Strength

The sole bond strength was tested to assess the strength of the bond by measuring how much force would be required to peel apart the bonded materials. The bonded specimens were trimmed to 25 mm wide, and the minimum load for separation of sole bonding ball girth area & toe area of a shoe was 25kg and measured on a tensile testing machine at a crosshead speed of 50 mm/min. Failure can occur at any one point of the possible sites. This test followed the SATRA TM411 standard[1,23].

2.2.9 Whole Shoe Flexing

This test was carried out based on SATRA TM184 using SATRA whole shoe flexing machine at room temperature (25°C). A suitable toe clamp is used to secure footwear to the machine at the toe end. The flexing bar is fastened to the heel end. Once the required number of flexes has been recorded, a predetermining counter that is installed will cause the machine to halt so that the shoe may be examined. The machine's moving parts are protected by a hinged guard that has the newest safety feature installed to prevent access while it is in operation[24,25].

2.2.10 Eyelet Pull-out Strength

With a universal testing machine, this test was conducted using the SATRA TM149. Footwear is sliced into a test specimen with eyelets. A length of lace is entered through the fastening, clamped in the second jaw, and a test specimen is placed between the machine's jaws. The amount of power necessary to cause the fastening to fail is calculated, and the failure type is noted[26].

2.2.11 Thermal Insulation Against Heat

Thermal insulation of footwear made of banana fabric & combination of leather and banana fabric was measured according to ISO 20344 using heat insulation tester instrument (Fig. 1). The footwear is used as the test piece. The temperature probe is fixed to the insole. The temperature inside the footwear is measured in the forepart in an area directly above the area where the sole contacts the hot plate. The steel balls are placed inside the footwear.

3 Results and Discussion

3.1 Performance Analysis

The analysis covered the tensile strength, stitch tear strength, tongue tear strength and elongation-at-break

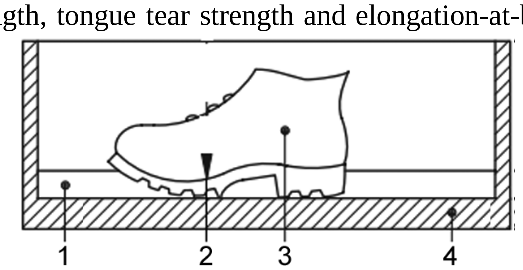

Fig. 1 — Heat insulation test apparatus [1-point for measuring temperature, 2- sandbath (height of sand ~30mm), 3-footwear filled with stainless steel balls, and 4- hot plate]

of the cow nubuck leather, goat nubuck leather, and banana fabrics (S1 & S2).

The mechanical properties of cow nubuck, goat nubuck leather and banana fabrics (S1 and S2) cut in the required dimensions and tested in parallel & perpendicular directions, are given in Table 2. It is worth noting that the tensile strength of banana fabrics (S1 & S2) is more significant in the parallel direction (along the warp) than in the perpendicular direction (along the weft). The weave style, fibre orientation, and fibre bonding affects the strength of woven fabrics[27]. When comparing both leather and banana textiles, banana fabric has higher tensile strength, with values ranging from 19.4N/mm^2 to 33.3 N/mm^2 in a parallel direction, while cow and goat nubuck leather values range from 15.01N/mm^2 to 18.3N/mm^2. Banana fabrics have substantially higher tensile strength than leather. The percentage elongation-at-break ranges from 18.9% to 22.1% for banana (S1 and S2) fabrics in both weaving directions. Cow and goat nubuck leather has a visco-elasticity attribute that allows it to elongate more than any of the tested banana textiles[28]. Because of closely packed fibres, the tear strength and stitch tear strength of cow and goat nubuck leather are larger than that of all the chosen Banana fabrics. Banana fabrics (S1 and S2) show tongue tear strengths ranging from 17.7N/mm to 20.3 N/mm in both weaving directions, according to Table 2. Based on the mechanical properties, S1 is found to be better than S2. Therefore, for further analysis S1fabric, cow nubuck leather and goat nubuck leather are selected.

3.2 FTIR Analysis

For banana fabric (S1), the spectra show bands at ~3300 cm^{-1} for O-H stretching absorption, ~2900 cm^{-1} for aliphatic methylene group C-H stretching absorption, and ~1600 cm^{-1} for C=C benzene stretching ring, ~1300 cm^{-1} for COO aromatic ester stretching, and ~1060 cm^{-1} for C-O-C stretching absorption. Due to the presence of cellulose and lignin respectively, the spectral bands at 1595 cm^{-1} and 1100 cm^{-1} are observed[29]. As a result, the current investigation indicates the presence of the necessary chemical components and functional groups in the fibre[30]. Carbonyl stretching band in cow nubuck leather, on the other hand, is visible at around 1630 cm^{-1}. NH stretching vibrations at around 3310 cm^{-1} and CH_2 stretching vibrations at around 2910 cm^{-1} are observed. Due to stretching and deformation of the C–N and NH aliphatic side chain amino acids in collagen, a band is appeared at 1542cm^{-1}. Samples of goat nubuck leather, on the other hand, shows a distinct collagen peak at 1655 and 1547cm^{-1}, which corresponds to amide I & amide III respectively. At 1450 cm^{-1}, the peak corresponds to the aliphatic side chains of amino acids that are abundant in collagen[7]. The peaks are shown in Fig. 2.

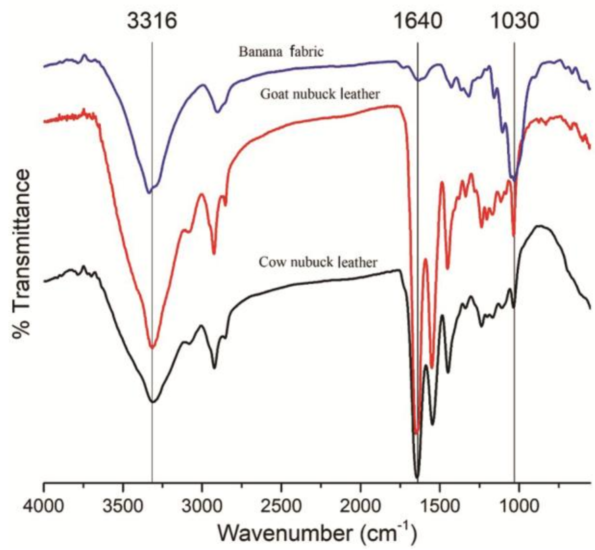

Fig. 2 — FTIR analysis of (a) banana fabric (S1), (b) cow nubuck leather and (c) goat nubuck leather

3.3 SEM Analysis

SEM has been used to examine the surface and cross-sectional view of the banana fabric, cow nubuck leather and goat nubuck leather, used in this study.

Figure 3(a) indicates the presence of individual fibre bundles with a smooth surface. The Smoothness of the banana fabrics might be due to the presence of oil and waxes on the surface[6, 31]. From Figs 3(b) and (c), the leather fibres seem to be thinner and a nap cover was observed[32] due to the abrasive treatment of the surface in nubuck leather.

Banana fabric [Fig. 4(a)] has a rectangular or square cross-section. The porous structure seen in the cross-section will increase the breathability of the material which is one of the prime requirements for the footwear application. The hair pores observed in Figs 4(b) and (c) might be due to the fibre bundles that are loosely packed and randomly interwoven in the cross section [33].

3.4 Thermogravimetric Analysis

The weight loss due to deterioration of the sample at various temperatures has been observed in the thermogravimetric study of banana fabric and leather. For banana fabrics, it is observed from Fig. 5(a), that the first weight loss of 9%, occurs around 100°C, is due to

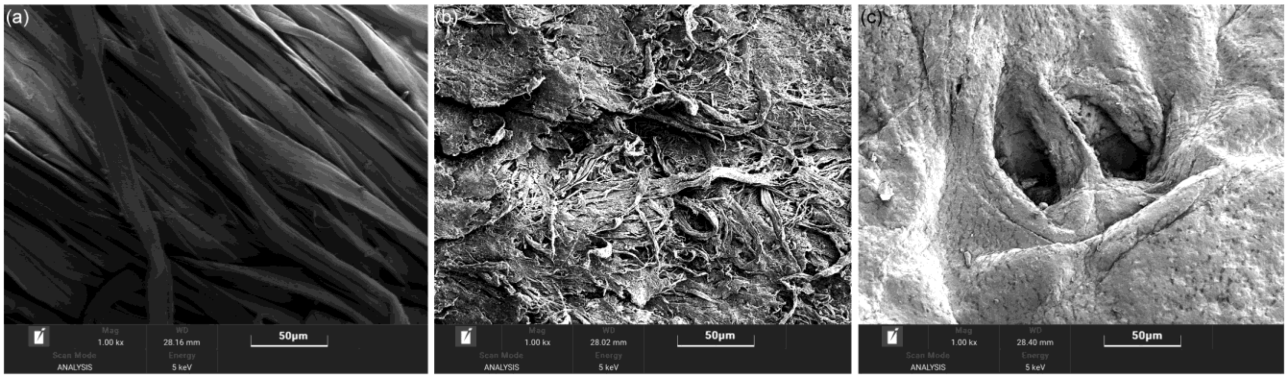

Fig. 3 — SEM images (surface:×50 um) of (a) banana fabric, (b) cow nubuck leather and (c) goat nubuck leather

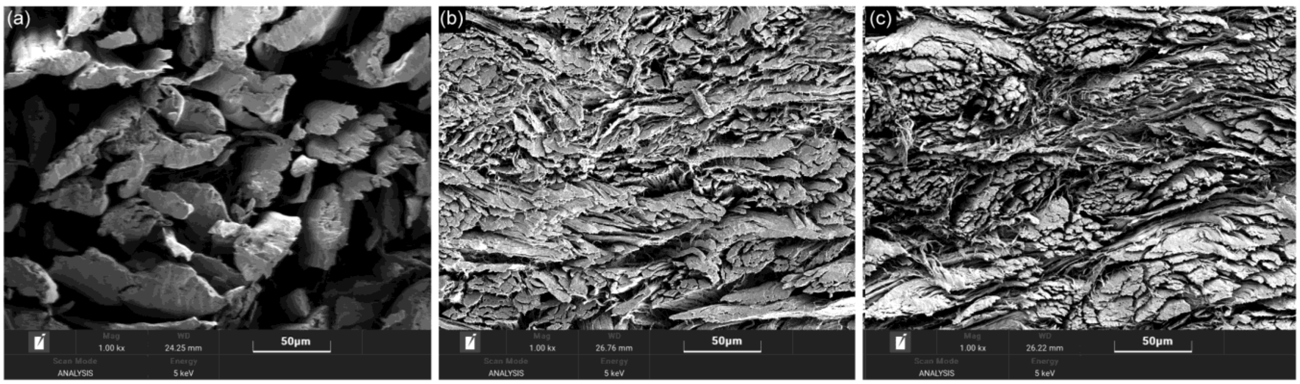

Fig. 4 — SEM images (cross-section: ×50 um) of (a) banana fabric, (b) cow nubuck leather and (c) goat nubuck leather

the loss of absorbed moisture. The second stage of weight loss is observed at around 290°C and continued up to 410°C due to the degradation of cellulose, hemicellulose, and lignin in the fibre. The TGA curves of cow nubuck leather demonstrate a two-stage weight reduction [Fig. 5(b)]. A 10% weight loss occurs in the first stage at temperatures ranging from 25°C to 100°C due to absorbed moisture. Beginning at 150°C, the second stage of weight loss is continued up to 500°C with a weight loss of 75%. There is a possibility that the protein's macromolecular structure has been damaged[28]. Maximum degradation occurs at around 344°C. The goat nubuck leather's TGA curve [Fig. 5(c)] exhibits a two-stage weight loss due to moisture loss and is thermally stable up to 250°C. As can be observed during the second step of weight reduction, the goat nubuck leather inflection point is 350°C (ref. 7). From the results, the thermal stability of banana fabric and goat nubuck leather is found comparable.

3.5 Product Performance Evaluation

3.5.1 Sole Bonding Strength and Eyelet Pull-out Strength

The shoes made out of banana fabric, leather and a combination of banana fabric and leather were

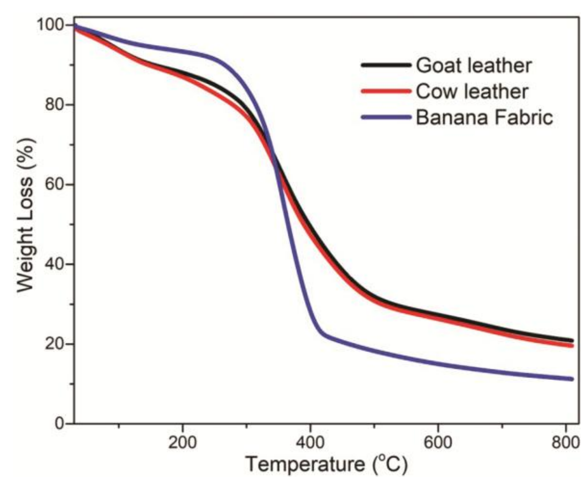

Fig. 5 — TGA curves of (a) banana fabric, (b) cow nubuck leather and (c) goat nubuck leather

subjected to strength testing. The results for sole bonding strength are shown in Table 3. SATRA recommends a minimum of 3.0 N/mm sole bonding strength[24]. From the results, it is interesting to note that shoes made out of banana fabric and a combination of banana fabric and leather are comparable to that of leather shoes. Therefore, banana fabric can be a good alternative to leather for footwear applications.

Eyelet pull-out strength testing is also carried out using a Universal testing machine based on SATRA TM 149. SATRA recommends a minimum of 20 N/mm eyelet pull-out. The results show that the values are far better than the standard.

3.5.2 Whole Shoe Flexing

Samples are subjected to 5,00,000 lakhs cycles of flexing and observed for presence of cracks along the thread line of the shoe[24]. It is noted that after 5,00,000 cycles, the shoes are found to be free from cracks in soles, whereas slight crack is observed in the upper of shoes made with banana fabric, leathers and combination products. Shoes made with banana fabrics and a combination of leather and banana fabrics have comparable flexural endurance.

3.5.3 Thermal Insulation Against Heat

When tested in accordance to ISO 20344, no cracks or deformation has been observed in the outsole as well as insole/insock of footwear.

The temperature differences of the test samples for different simulated atmospheric temperatures are given in Table 4. Lesser value indicates better thermal insulation. These studies reveal that the leather has better thermal insulation than that of the banana fabrics. However, when banana fabrics are combined with leather, the thermal insulation of banana fabrics improves. It is evident that leather, in general, possesses good thermal insulation characteristics due to the spatial form (3D) features of collagen fibres, which holds large amounts of air inside the fibre network. From the thermal insulation values of all leathers and their microscopic structures, it is evident that the more organized and dense fibre packing in cow nubuck leather provides better thermal insulation[34].

Thermal insulation increases with increase in area density in all types of fabrics. Thermal insulation increases with the increase of material mass, i.e. fibre which itself is a good thermal insulator[35]. The thermal conductivity of banana is lowest, which may be because of its higher thickness. So, banana fabrics can be used in combination with leather for requirements related to thermal insulation.

4 Conclusion

The purpose of this study is to evaluate the main features of chosen banana fabrics for their potential to combine with leather for footwear applications. The findings of this investigation indicate that banana fabric has high tensile strength values comparable to cow nubuck leather and goat nubuck leather, proving its suitability for use in leather footwear. The tensile strength (ranges from 19.4N/mm^2 to 33.3 N/mm) for banana fabrics, cow nubuck leather and goat nubuck leather remain direction-dependent, according to physical property results. Tensile strength of the selected banana fabrics (S1 & S2) remains significantly superior to that of cow nubuck and goat nubuck leather. Cow nubuck leather and goat nubuck leather have a higher percentage of elongation than any of the chosen banana fabrics. The double hole stitch tear strength of cow nubuck leather and goat nubuck leather is greater than that of selected banana fabrics in both directions. However, the tongue tear strength (ranges from 42.9±0.4 to 137.6±1.6) of cow nubuck leather and goat nubuck leather are equivalent to that of banana fabrics. According to TGA tests, the banana fabric has more excellent heat stability than cow nubuck and goat nubuck leather. Surprisingly, the chosen banana fabric has a two-stage degradation, indicating the presence of a single natural fibre. This study would confirm that the selected banana fabric could be combined with leather for leather footwear applications. As a result, the shoes made with banana fabric and banana fabric combination with leather exhibit better properties and are quite comparable to leather, indicating that the banana fabrics could be used in footwear fabrication.

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