Final Report

Application of Vegan Leathers for Cricket Balls and Gloves

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Executive Summary

The findings presented in this report form part of the UKRI CE-Hub flexible fund's feasibility study on Circular Cricket Gear (CCG) led by The Centre for Sustainable Design ® (CfSD) at University for the Creative Arts (UCA). The CCG project aims to develop potential strategies to maintain the value of products, components, and materials in the economic and social systems of cricket gear, as well as explore material innovation for cricket gloves, batting pads and balls. This report builds on findings from the Platform for Acceleration of Sustainability in Cricket (PASIC) and the Vegan Leather Cricket Gear project (VLCG).

The scope of this investigation is limited to the application of sustainable biomaterial leather alternatives to cricket balls and gloves. Other cricket gear, such as pads, were excluded as while bovine leather may have been traditionally used in these products, it is no longer the material choice. Initial research focused on developing an understanding of the qualities of bovine leather that make it suitable for cricket gear applications, namely durability, strength, breathability, abrasion resistance, and environmental resistance. Through interactions with diverse stakeholders, including cricket gear manufacturers, it became apparent that an alternative biomaterial alternative needs to 'replicate' bovine leather's behaviour, rather than 'outperform' it.

The leather alternatives sector is a rapidly growing biotech industry, with a large number of players and potential solutions from diverse resources. Market research identified 87 companies producing 123 different materials as self-proclaimed leather alternatives. The main biological components of these materials fell into 6 categories: fungus, plant stem, fruit and leaves, fish, and other which includes unique or unknown components. Most notably, the intended use of almost all of these leather alternative materials is in fashion or upholstery, with no evidence or prior interest of use in performance applications such as sport. Moreover, while there are a large number of players and innovations, publicly available information on these new alternative leathers (e.g. manufacturing process, properties, sustainability credentials) is scarce, as many companies are in early research and development or commercialisation stages. In many cases, even acquisition of samples was not possible.

This project set out to perform rigorous materials testing of a few biomaterial leather alternatives for applications in casings of cricket balls and palms of batting glove and inners. This project tested five material groups: Bananatex (from abaca banana leaf fibres), BarkTex (from tree bark fibres), Hide BioTech (from reconstituted proteins from waste fish), Piñatex (from pineapple leaf fibres), and finally, bovine leather (industry benchmark). With the application of cricket balls and gloves in mind, the most important properties to consider were thickness, tensile strength, stitchability, abrasion resistance, and interaction with water.

The principal conclusion is that whilst some of the alternative leathers tested show potential, their performance is not par with bovine leathers for cricket gear applications. The authours note that these alternative leathers were not specifically synthesised or designed for performance applications, and only a limited variety of biomaterial leather alternatives were tested in this project. A further dedicated programme of research is necessary to test, and even synthesise new fully-functional leather alternatives for performance cricket gear.

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1 Introduction

Ongoing criticism of the leather industry, due to its mistreatment of animals and adverse environmental effects has led to some members of the public pledging to avoid using the material. As the popularity of veganism [1] and awareness of the global environmental crisis increases, the pressures on cultures and industries to implement sustainability values and sustainable innovations will also increase.

A prime case study of this is the cricket Industry, as it is a gear-intensive sport grounded in traditional values. Even the most casual youth players require balls, gloves, bats, helmets, and protective pads, so the potential impact of increasing the sustainability of cricket gear is massive, given it is the second most popular sport in the world.

The findings presented in this report form part of the UKRI CE-Hub flexible fund's feasibility study on Circular Cricket Gear (CCG) which aims to develop potential strategies to maintain the value of products, components, and materials in the economic and social systems of cricket gear, as well as explore material innovation for cricket gloves, batting pads and balls. This report builds on findings from the Platform for Acceleration of Sustainability in Cricket (PASIC)[1,2] and the Vegan Leather Cricket Gear project (VLCG) [1], both led by The Centre for Sustainable Design ® (CfSD) at University for the Creative Arts (UCA).

1.1 Motivation

Over 300 million people regularly play cricket, the majority in low and middle income nations. Cricket is one of the most equipment-intensive sports: each of the over 40 types of cricket gear [2,3] comprises multiple component materials that are derived, processed and assembled through complex supply-chains, and notably, designed without consideration for end-of-life disposal. Consequently, cricket gear production and disposal are likely to have a significant impact on the environment.

Being a sport bound strongly by traditions, change is often slow in cricket. This is also true of the gear used for cricket. Some cricket gear, such as pads and apparel, have evolved over the past half century with the advent of high-performance and lighter-weight polymeric materials which can be produced in the form of foams and textiles. Other materials, such as willow in the blade of bats and bovine leather in the casing of balls, have remained virtually unchanged for centuries. Change in cricket gear may be initiated by advancements in material and process technologies, but requires support from all stakeholders, including the rule-makers (e.g. Marylebone Cricket Club), manufacturers, players and officials, and supporters.

Marylebone Cricket Club (MCC), the organisation that defines the laws of cricket[5], has recently, in November 2022, appointed a new Sustainability and Accessibility Manager to lead the club in the push for sustainability and access[6]. Supporters of the sport and players are

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[1] Taylor, B., and Shah, D. (2023) Leather Alternatives for Cricket Gear.

[2] Charter, M. and Clark, T. (2022), Sustainability, Cricket Gear, Clothing and Apparel: Report on Cricket Gear.

[3] Wetherfield, M., Charter, M., Shah, D., Whitaker, C. (2022) Sustainability, Cricket Gear, Clothing and Apparel: Report on Components, Materials, and Innovation Opportunities.

also increasingly aware of environmental challenges and are willing to make choices that lead to better environmental outcomes: for example, a survey of cricket players as part of the Vegan Leather Cricket Gear project suggests that over 70% of players would consider replacing their existing gear for a plant-based vegan leather alternative. This was based on a relatively small sample and respondents were an older demographic compared to the mean recreational playing age which makes the positive response even more encouraging. The main perceived barriers to application were the quality of materials, with many having a preconceived notion that vegan leather alternatives may not be as well performing as the conventional leather materials. Manufacturers are also making efforts to demonstrate sustainable practices and developed new sustainable solutions: Gray Nicolls, for example, have developed Off-Cut batting gloves from upcycled pieces of materials. Stakeholders are slowly but surely moving towards change.

The Centre for Sustainable Design ® at UCA initiated the Circular Cricket Gear project[7], which aims to catalyse and support the acceleration of circularity-driven innovation in cricket equipment. This project involves collaboration between many major organisations, including cricket gear manufacturer Gunn & Moore[8], Piñatex producer Ananas Anam[9] , and the British Association for Sustainable Sport[10]. These three organisations bring together the required expertise to enable the development of a clear plan for increasing the circularity, and therefore sustainability, of the cricket industry.

Cricket ball casings and the palms of batting gloves are exclusively made from bovine leather. As a part of the larger investigation into circular cricket gear, this project specifically looks at replacing bovine leather with alternative biomaterials for cricket balls and gloves. These biomaterials would ideally be more environmentally friendly in production, use, and end of life, often utilising waste streams, avoiding toxic processing chemicals, and possessing superior biodegradability.

The specific focus of this project is to explore sustainable leather alternatives to replace the leather used in cricket balls and gloves. Balls and gloves were selected as the primary focus of this project as they are the products in which leather is commonly used. Almost no cricket pads still use leather, hence pads were excluded from the scope of this project. This narrowing down of scope facilitated more in-depth analysis of these two applications and ensured testing was relevant to both applications, providing useful insights into the potential for implementing the use of alternative materials.

For the purpose of this project, sustainable leather alternatives are defined as any material that are ‘marketed’ (self-proclaimed) as being biologically based, sustainable, and a suitable alternative to leather. Any materials that, upon deeper research, are found to include significant proportions of plastic or other unsustainable materials are excluded.

1.2 Project Aims

The three main aims of this project were to:

1. Investigate the properties of the leather that is currently used in cricket gear.
2. Explore a variety of biomaterials and compare their material properties to benchmarks defined in Aim 1.

3. Assess the feasibility of replacing leather in cricket balls and gloves with a biomaterial identified in Aim 2.

1.3 Report Structure

This report will initially present the theoretical framework behind this investigation, including the scientific background behind the leather industry, potential sustainable alternatives, and the most pertinent regulations in cricket. It then goes on to explain the process of developing suitable testing methods and presents the results obtained from this experimental research. These results are discussed in the context of the application, with recommendations being made for the best alternative materials for both cricket balls and cricket gloves. These recommendations are summarised in the concluding statements, alongside recommendations for suitable future work.

2 Theoretical Framework

The theoretical framework behind this project comprises three main areas:

1. Understand leather as a material
2. Understand what alternative biomaterials to leather are available in the market, and the information that is presently known about these materials.
3. Understand the functions and any specifications of leather in cricket gear (balls and gloves).

2.1 Replacing Leather

Commonly notable properties of leather include durability, strength, toughness, breathability, and environmental resistance. These properties are why leather is widely regarded as unique and irreplicable, generating 32.65% of revenue in the footwear industry[14]. In cricket, it is used primarily in gloves and balls, with its use in cricket pads reducing in recent years due to the increasing popularity of plastic alternatives such as polyvinyl chloride and polyurethane high-density foam, paired with cotton and canes[15] .

2.1.1 Microstructure of Leather

Leather's biological origin introduces a considerable amount of variability into its material properties. It has a hierarchical structure made of long, thick collagen fibres that are grouped into fibre bundles and interwoven in three dimensions[16]. Structural variations exist within the material itself, with the densest material present at the skin's surface in the 'grain'. This is one of the two main layers in leather, alongside the corium, which is the dermal layer nearer the bottom, adjacent to the flesh. Fibres are packed tighter in the grain and stand up nearly vertically, whereas within the corium, they lie almost horizontally and are more loosely packed. Typically, the proportion of vertical fibres is an indication of the leather's durability[17]. This structure is shown in figure 1 below.

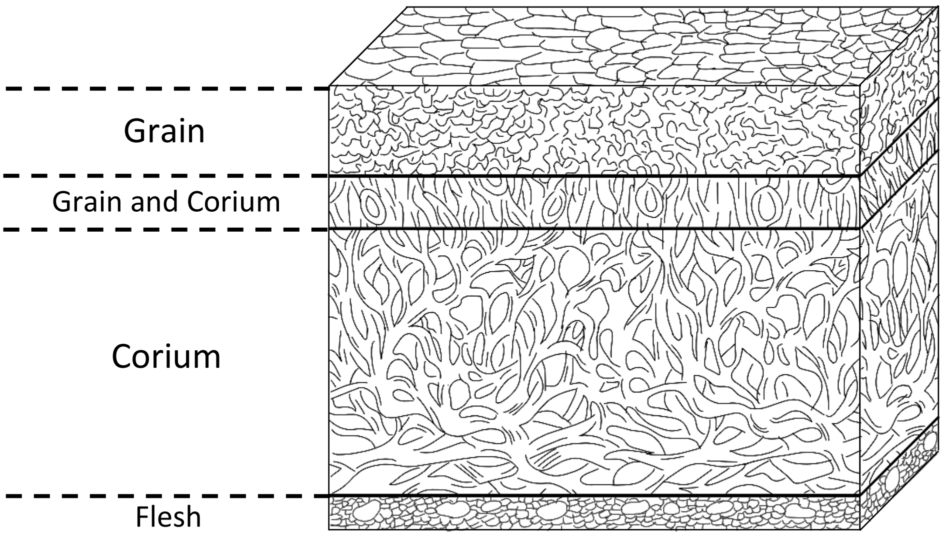


Figure 1: An illustration of the microstructure of leather, with annotations identifying the major features.

As can be seen in Figure 1, the microstructure of hide or skin remains present in processed leather[18], causing well known anisotropic[4] mechanical properties on several scales[19]. Different breeds and 'cuts' of hide have a variety of tensile properties in different directions; however, Dietrich et al [19] found no clear trend in the differences in the failure stress and strain for leather from the back and flank, cut both parallel and perpendicular to the spine. Encouragingly, they also found that the initial slope of the stress-strain curves was consistent across all combinations of hide sections and cutting directions. This indicates that comparisons can be made between this initial slope and the slope of the alternative materials investigated without needing to determine the hide area and cutting direction of the leather tested. The combination of this research with the difficulties in obtaining such information about the leather samples received means that any effects of anisotropy on materials properties have been neglected.

It is also clear in figure 1 that there is a variety of porosity within the layers, with natural leathers having nano-, micro-, and macropores that range from 0.3 nm to 150 µm[16]. Leather features amino acids that have both positively and negatively charged side chains, contributing to a hydrophilic nature, which is integral to its natural function but also provides manufacturers with breathability. The skin matrix contains five levels of hydration, with some of this bound water remaining when leather is dried at 100 °C. This hydration is reduced during tanning, where tanning agents such as chromium or aluminium salts are reacted with collagen to stabilise the fibres, leaving the leather with a lower moisture content and increased hydrophobicity[20].

2.1.2 Impact of Leather Processing

Leather for cricket balls is tanned using aluminium salts, which is known as alum-tanning or tawing. While it is a naturally occurring salt, it is also artificially produced[21]. This process leaves the leather stiff as, while no complex bond is formed between the collagen and the

[4] Different properties in different directions

aluminium sulphate, there is high astringency, so the fibre structure tightens[22]. Alum-tanning also leaves leather white in colour. Further treatment, such as greasing and dyeing, is then conducted to turn this stiff white leather into the familiar red leather on the outside of cricket balls.

Critics of the leather industry voice the cruelty it inflicts on animals and people. There is also a common misconception about leather: the leather skin is thought of as a waste-product of the meat industry. However, in reality, all parts of the slaughtered cow are sold for profit, and therefore the selling of skins can be seen as subsidising the meat industry and contributing to animal cruelty. For some animals, the skin can be worth 80% of its total value, with meat then becoming the by-product. Roughly one billion animals are estimated to be slaughtered for their skin worldwide[23]. Additionally, working conditions in tanneries can be sub-standard and harmful. 85–90% of leather is created using chrome tanning, which can involve the use of toxic and polluting agents, specifically chromium III. This method is so dominant because it is a much quicker process than vegetable tanning. Chrome-tanned leather is also easier to make hydrophobic (water resistant) and can be softened more easily. Typically, the chrome-tanning agent will contain 33% basic chromium sulphate and 26% chromium (III) oxide. Up to 50% of the chromium used by some commercial operations can find its way into the environment, being consumed by animals and subsequently humans. This is a substantial amount given that 480,000 tonnes of chrome-tanning agent are produced annually.

Tannery workers, which can include children as young as 10[24], have a higher morbidity (40.1%) than reference values (19.6%). This is thought to be due to the presence of leather dust in the atmosphere in the tanneries, which is certainly feasible given that tannery workers also show high levels of respiratory illness (16.7% compared to 4.27%). The lungs rapidly absorb hexavalent chromium, allowing it to penetrate cellular membranes, bind to haemoglobin, and affect the capacity of the blood to carry oxygen. It can also cause kidney and liver damage, cancer, and reproductive problems. The effects of this chemical are not limited to the workers; harmful levels of hexavalent chromium were found in 25% of chickens in Bangladesh[25], a country that is home to the large tanning region of Hazaribagh, which contains 200 separate tanneries.

The disadvantages of the leather industry extend beyond impacts on animals and people. There are significant environmental issues associated with the use of resources such as food, land, and water. Laurenti et al.[26] calculated that the three tanneries investigated that used chromium tanning and processed raw hide into leather all had water footprints over 135 litres/m^2. On top of this, the leather industry actively emits harmful substances into the environment, both explicitly and implicitly. The carbon footprints for the three tanneries investigated by Laurenti et al.[26] varied as they all sourced significant amounts of energy from the grid, and these grids were in different countries, which have a range of CO_2 emission factors. For example, the Australian tannery investigated has a carbon footprint of 12 kg CO_2–eq/ m^2, compared to the Spanish tannery, which emits 2.5 kg CO_2 –eq/ m^2. Part of this difference is attributed to the Australian tannery's processing of exotic hides, which causes them to be more energy intensive (49 MJ/m^2 compared to 30 MJ/m^2), but the majority is due to the inherent CO_2 emissions of the energy grid.

To fully appreciate the negative environmental impact that the leather industry has, it is important to consider the source of the leather. Typically, the supply chain of leather will consist of cattle farming, slaughtering, leather tanning, product manufacturing, distribution, retail, and finally consumer use[27]. Cattle farming is a driving force behind deforestation, reduced biodiversity, and reduced food production. It also directly contributes to greenhouse gas emissions, representing 65% of the livestock sector's emissions, which as a whole make up 14.5% of all anthropogenic emissions[28]. Deforestation is particularly concentrated in Brazil; the Amazon rainforest, one of the world's greatest carbon sinks, is now emitting more carbon dioxide than it can absorb because of deforestation[29].

The negative environmental consequences of the leather industry are clear. With Charter and Clark[30] estimating 1,800,000 balls, 300,000 batting gloves and 50,000 wicket keeping gloves go to waste each year, it is important to innovate to assess whether leather is necessary in these products.

2.1.3 Sustainability Metrics

As was shown by Charter and Sanchez Moreno[31] in their investigation into sustainability in cricket gear, clothing, and apparel, there are no existing and commonly used sustainability metrics for material use in the cricketing industry. This investigation was based on a selection of presentations conducted in line with the goals of the Platform for the Acceleration of Sustainable Innovation in Cricket (PASIC)[7]. A later paper explores the specific challenges of sustainable cricket gear, and it is in this paper that the authors estimate the amount of waste gear generated annually[30].

As the goals of this project are focused on the feasibility of replacing leather with an alternative material, instead of the potential impact of such a choice, an exact, quantified sustainability metric will not be defined or used within this report. The required life cycle assessment to comprehensively define such a metric is a separate but equally important line of research that is being conducted as a part of the wider project on sustainability within cricket[12].

Despite this exclusion, it is still imperative that the alternative materials offer a sustainable advantage over leather itself. The material selection methodology is outlined in detail in Section 1.3 and includes requirements for the material to not contain a significant quantity of plastic and the primary material to be bio-based. These requirements can be assumed to give alternative materials an environmental advantage over traditional leather.

2.1.4 Specific Material Properties

The replication of leather's material properties was the prime focus of this project. These properties are easily identified from leather's use in daily life and include durability, strength, and environmental resistance, which include properties such as permeability to water vapour, hydrophilicity, and the ability to withstand weather and other environmental factors. In cricket specifically, the ability for the casing material of a ball to be lacquered and shined is important, alongside machinability and ' stitchability', defined as the ability of the material to be held in place with stitches.

Even if an alternative material were to replicate leather's properties and therefore be a perfect replacement theoretically, a successful alternative material will also have to be accepted by stakeholders such as manufacturers, industry managers, coaches, and players. For users of the product, the most important factors are how the cricket gear appears, feels, and behaves. Cricket is a sport with long-standing and heavily embedded traditions, which means a new alternative that does not look like the original gear would not be easily integrated into the sport. The introduction of a new material into the cricket gear manufacturing industry will require compatibility with the existing infrastructure. The reasons for this are twofold: it should be easy for manufacturers to begin to use this material to ensure a quick uptake once it is introduced, and it would be significantly detrimental to the positive environmental impact that these new alternative materials could have over leather if large structural changes had to be made to the existing infrastructure, as this would cause large amounts of material and resources to go to waste.

Prototyping a material that theoretically replicates leather perfectly may reveal that the interaction between the new material and the other components of the ball or glove causes unwanted effects on the products' overall performance. To mitigate this, the alternative materials will be tested against glove and ball leather so that direct comparisons can be made. This investigation aims to provide recommendations for the materials that should be prioritised in any future prototyping by assessing which are most likely to replace leather effectively.

2.1.5 Inspiration from Other Investigations

Initial inspiration for this project was found in the ongoing project directed by Professor Martin Charter, Director of CfSD at the UCA that is investigating the circular design of cricket gear. His report, in collaboration with Tom Clark[30], highlights the significant sustainability issues in the cricket gear industry and the diverse range of stakeholders that must be brought together to make a substantial impact on the game going forward. Many of their recommendations call for further research to be conducted into the industry, as there is a clear lack of publicly available information about the materials and resources used in cricket gear.

Preliminary reading into the area revealed a relevant, informal project with a slightly different focus, led by Gary Shacklady, the Chair of Early Cricket Club[32]. Shacklady's motivation was to find a vegan alternative to leather cricket gear, and he included vegan, fossil-fuel derived plastic-based materials in his search. Notably, fossil-fuel derived plastics-based leather alternative materials have been excluded in this study. A lack of materials, resources, and spare time limited the work that could be completed by Shacklady and his team. At the time of their research, most bio-based materials were being produced by small companies that were not producing enough to be able to provide samples for research. Additionally, the pandemic made international companies more difficult to work with. Shacklady et al. investigated alternative materials based on mango, apple, coconut, and pineapple, all of which were aesthetically similar to leather but not designed or tested for impact or abrasion properties. Absorption, deterioration, and thickness were all noted as essential material properties where alternative materials often fell short. In the end, Shacklady et al. were able to create a prototype vegan ball using polyurethane material that claimed to be biodegradable; in testing, it was shown to be bouncier than a standard ball. This subtle difference in material properties clearly had a massive effect on the game, highlighting how imperative it is for an alternative material to not focus on optimising properties but instead focus on replicating both the positive and negative properties of leather as closely as possible.

2.2 Potential Alternative Biomaterials

The initial investigation in this area consisted primarily of in-depth market research to quantify the scope of currently available biomaterials that are marketed as alternatives to traditional animal leather. Most of these materials are currently aiming to be implemented in fashion or upholstery. While the fashion application includes shoes, the application of alternative materials in sports gear has not been investigated previously. Materials used in sports often require high performance properties and uniformity across material samples and final products. This uniformity is inherently difficult to achieve when utilising materials that are naturally derived.

For this market research, papers, articles, and websites were sourced primarily from Google and Google Scholar. A selection of keywords were used in searches: sustainable, leather, alternative, vegan, material, bio-based, biomaterial. Another major source of materials was the Material Innovation Initiative website[33], which was revealed during internal communications. Materials that were known to not be predominantly bio-based were excluded; however, the lack of clear information about many of the materials found makes comprehensive exclusion of such materials impossible. This market research was conducted at the end of 2022; therefore, due to the volatility of the constantly changing biomaterials market, it is possible that materials have been included that are no longer in development.

87 companies producing 123 different materials were found. Many of these were missing basic information, sometimes even the company or material name. The sources used to conduct this market research were frequently websites or blogs, which have the potential to be unreliable. Often the only source of information was the company's own website, which introduces the potential for hyperbolic and misleading information, given the website's primary purpose is to persuade investors, companies, and consumers to support the business.

A simple classification system was derived to categorise the various materials. 8 categories were devised based on the key biological component of the leather alternative material: fungus-based (e.g. Fine Mycellium™ by MycoWorks), leaf-based (e.g. Pinatex® from waste pineapple leaf fibres from the Philippines, Desserto® from Mexican cactus leaves[5], and Bananatex® cultivated Abaca leaves in the Philippines[6]), fruit/vegetable/flower-based (e.g. AppleSkin and GrapeSkin), other plant-based, fish scales/shells-based (e.g. Hide Biotech), cell cultured, and other/varying composition. Within each category, four sub-categories were identified: waste-based, grown, harvested, and unknown. Example materials for each of the main component categories are illustrated below in Figure 2, which also indicates how these categories are linked by materials that utilise multiple components. The full database with

[5] https://desserto.com.mx/why-desserto%3F
[6] https://www.bananatex.info/

known material compositions, properties and production locations amongst other characteristics are found in the VLCG report [7].

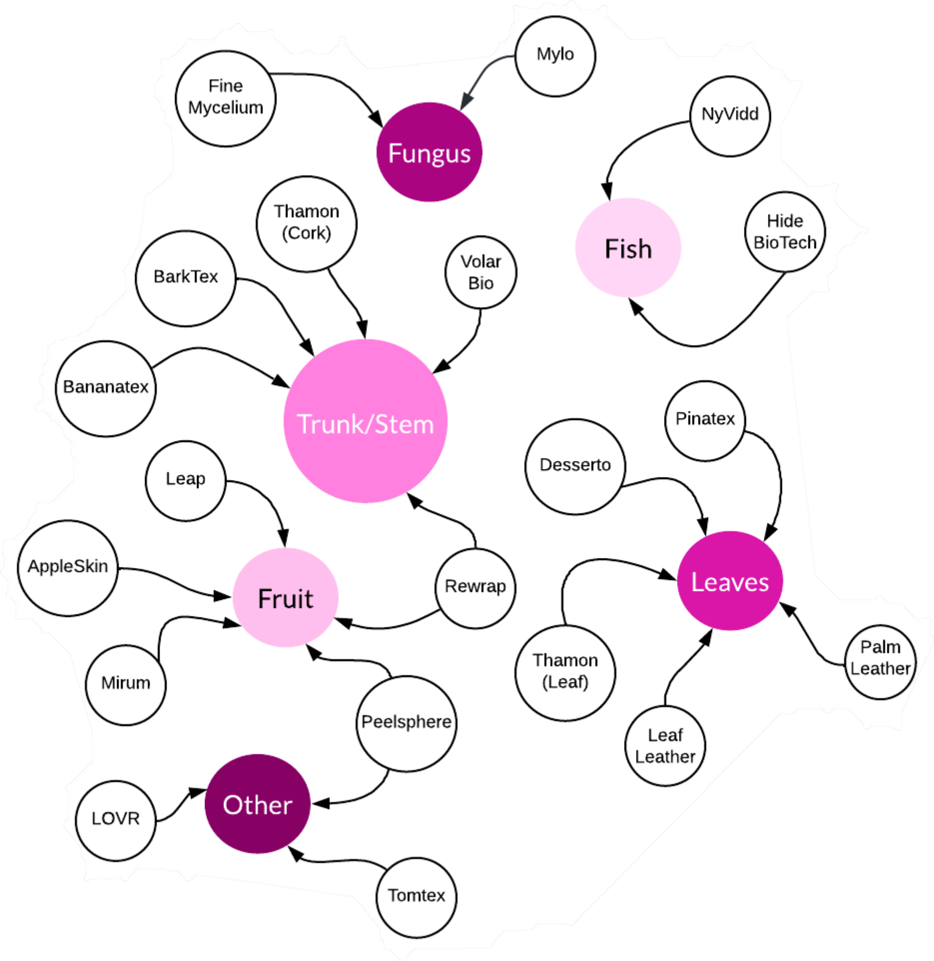


Figure 2: A schematic of the main categories of biological components used in alternative materials, with example materials for each component type indicated.[9, 33-50]

It is worth noting that in some ways the classification system adopted reflects the generic biotechnology processing methods that may be adopted to synthesise these biomaterial alternative leathers. For example, leaf fibre-based leathers (e.g. pineapple leaf fibre based Pinatex, or abaca leaf fibre based Bananatex) require generic steps such as: waste/leaf collection, extraction of fibres through mechanical processes, subsequent washing, drying and purification of fibres, combining with some other (typically petrochemically derived) polymers or coatings to impart water repellence and durability, and conversion in textiles (such as nonwoven felts or woven fabrics). Fungal leathers require generic steps such as selection of specific fungal strains and growing media, purification of a mould, growth of fungal strain on growing media, heating and drying of the mycelium and demoulding. Fish based leathers typically adopt reconstitution of proteins into sheets such as through casting processes. It is thought that fruit-based leathers have generic steps such as waste collection (pomace or pulp residue of pressed fruit or extracted juice), purification, drying and powdering, followed by mixing and combining with other materials to form textiles or sheets. More research is needed

[7] Taylor, B., and Shah, D. (2023) Leather Alternatives for Cricket Gear.

in this area to compare, analyse, evaluate and streamline the manufacturing processes of the various biomaterial leather alternative materials.

It is also worth noting that while these are all biomaterial alternatives, not all these leathers are necessarily more ‘sustainable’. Their sustainability needs assessment and more research is needed in this area. Indeed, many of the leather alternatives use a non-trivial proportion of fossil-fuel derived plastic component (ranging from typically 30-60%). Even ‘waste’ is a term that may need further clarification or discussion. For example, waste fish-based leathers have a very similar production process to the bovine leather currently used in cricket gear, just using a different animal. Currently, the companies that are manufacturing waste fish-based leather can boast an environmental advantage as they are utilising waste skins from the fishing industry, typically from Scandinavian countries and Japan. If these skins are being purchased from the fish companies, there is a grey area in which this sustainable alternative could begin to drive an increase in fishing to source more skins for leather. If this were to become the case, this could grow and create similar issues as in the bovine leather industry. However, in contrast, fruit ‘waste’ is likely to be consistently more environmentally friendly.

It is clear from the number of companies conducting research in this area and the variety of biological components used that this is a vast and fast-growing industry. This indicates huge potential for material development, which could easily facilitate the opportunity to fine-tune materials’ properties to tailor them for specific applications.

While a huge variety of materials were included in this initial research, very few companies were in a position to be able to provide samples for testing. Requests for samples were sent to all companies with information about their materials on their websites. Alongside these requests, an existing connection with Hide BioTech facilitated a partnership that allowed the design of two materials, tailored to the cricket gear applications. They were even able to create the red material, which was an appropriate thickness for a cricket ball and the thickest material they had ever manufactured. This was particularly notable as the majority of alternative materials were not available in the required thickness of at least 3 mm due to production and manufacturing restraints. Such a collaboration demonstrates that more such partnerships are needed to co-create novel leather alternative biomaterials specifically for cricket gear applications.

A full table of the material samples received and tested in this report is presented in Section 3, Materials.

2.3 Leather and Alternative Materials in Cricket

The key properties relevant for leathers in cricket balls and gloves are presented in the Figure 3. Initial inspiration was sought from the standards and specifications available for the application that require cricket balls to use alum-tanned leather to enclose a core[13], assuming leather is defined by BS EN 15987 as “Hide or skin with its original fibrous structure more or less intact, tanned to be imputrescible”[51]. The MCC only specify the dimensional requirements of balls for men, women, and junior games[5] and so provide no further requirements. Evidently, under the current British Standards, the use of an alternative leather that was not made of hide or skin would not be permitted in cricket.

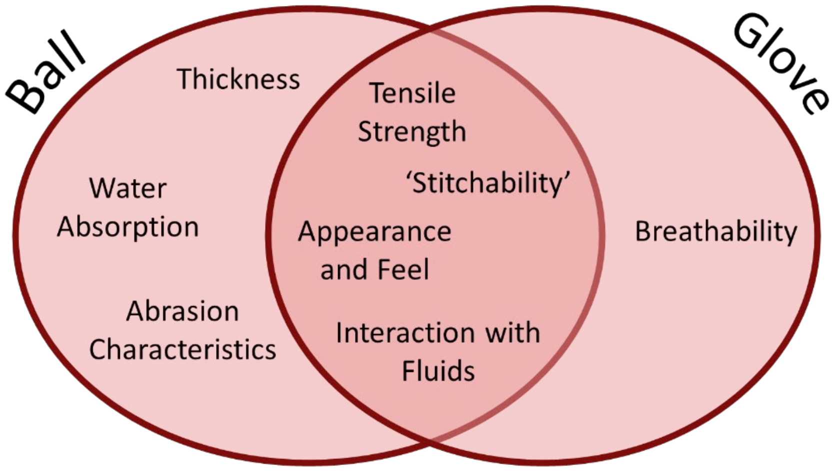


Figure 3: A Venn Diagram showing typical performance and property requirements of leathers used for cricket ball casings and batting glove palms.

Thickness is a particularly pertinent property, as many of the alternative materials available are not thick enough to replicate real leather. The thickness of leather used is determined by the ability to place stitches within the material, as specified in BS 5993:1994[13]. This can be linked to the 'stitchability' of the material, which assesses the material's performance in stitching. Other important factors that feed into 'stitchability' are the tensile and tear resistance of the material, as well as the resistance the material gives to a needle, which is likely to depend on the density and porosity of the material.

As cricket gear is used outside and in contact with skin, a material's interaction with water and other fluids is important to investigate. This property is particularly important when considering the application of cricket gloves, which are in close contact with sweat and are often marketed as breathable. The alternative material most suited to cricket gloves is likely to be different from the one suited to cricket balls, as there is less emphasis on thickness and more on breathability and interaction with fluids.

It is also imperative to consider how the alternative material looks, as this has a clear effect on the feasibility of achieving buy-in from certain stakeholders such as coaches, players, and umpires. The market research conducted indicated that some materials very closely replicate the appearance of leather, whereas others provide similar properties without attempting to look similar. While appearance does not have any effect on the objective ability of the material to fulfil the requirements of the application, it will clearly influence the feasibility of replacing leather because of people's innate resistance to change.

Successful adoption will require the ability to demonstrate the significance of the impact that changing these materials could have. For initial adoption, it may be favourable to use a vegan material if possible, so that marketing can use both the sustainability and animal-friendly benefits to increase interest and, therefore, adoption. Organisational stakeholders, such as manufacturers, will have different priorities, focusing mainly on ease of integration. This places specific requirements on the material selected to be able to be manipulated in the same way as leather. Lack of abrasion resistance or a significant reduction in tensile strength could cause issues within the manufacturing process as the processing techniques could damage the material. Kookaburra Sport[53] outlines some elements of the traditional manufacturing process used by Kookaburra, the company that produces the majority of test match balls. They use heavy leather steer hide, which is hand selected, tanned, dyed, cut, and shaped into hemispheres that form the two halves of the ball. These hemispheres are stitched at this stage to ensure they hold their hemispheric shape. Once the core is made, the two hemispheres are hand paired around a core and are hand stitched together with linen, using the same technique as was used in 1890. The final step is the addition of a nitrocellulose lacquer, after which the balls are polished.

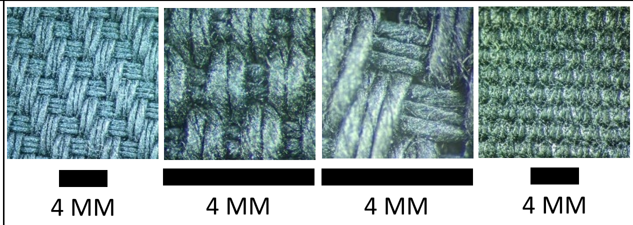
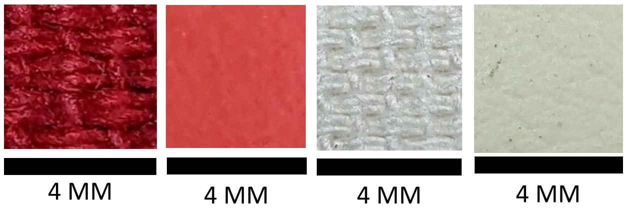
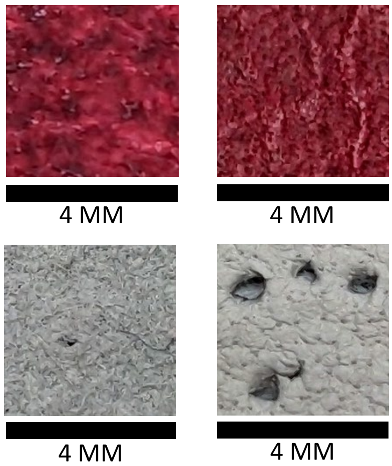
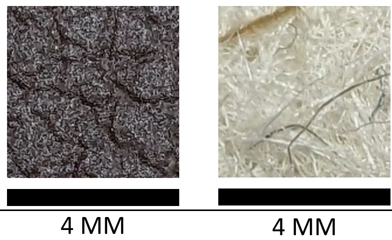
The moulding of leather into the required hemispheres requires tensile strength and elasticity to ensure the material does not fail during this step. The stitching of these hemispheres means the material must be able to withstand the concentration of stress around the seam and still retain its tensile strength. If the material has low seam tensile strength, it will fail when the ball is assembled. There are very few people globally who can hand-stitch the seam on cricket balls, making their opinions of any future innovation incredibly important. To appease this stakeholder group, it is imperative that the material look and feel like leather, particularly when moulded into hemispherical shapes. Factors such as the resistance to the needle and the ability for the material to be sewed in the same manner as leather are essential to investigate in future research when prototypes are manufactured.

The final step in this process is the addition of lacquer. Each company uses a slightly different lacquer, and the exact ingredients are often kept secret, as some companies, such as Dukes, use traditional unpublished recipes[54]. This project aims to conduct materials testing to lay the groundwork for future research into this area, so the interaction between alternative materials and these lacquers is not investigated. However, this is an essential property to consider and should be the focus of a future piece of research. This may require collaboration with major manufacturers such as Gunn & Moore, Kookaburra, and Dukes, and so may be delayed until there is significant evidence that the alternative materials are able to meet all other requirements, both on their own and as part of a prototype.

Perhaps most influential are the British Standards, which, as indicated previously, currently bar the use of alternative materials in official cricket balls. Significant reform would be required to implement this change of material in high-level cricket, a step that could prove essential to take as high-profile users of such gear would have a huge influence on lower profile users. Currently, the British Standards do not specify that leather must be used in cricket gloves, so research into replacing leather in cricket gloves should be prioritised in the immediate future. Alongside this research, discussions should be had with influential stakeholders to attempt to reform the standards to support research into using alternative materials instead of the leather in cricket balls. This initial focus on replacing glove leather is compatible with the delay in ball prototype testing due to the use of lacquer mentioned above.

3 Materials tested in this report

A full list of the materials tested is given in table 1, with the material's properties presented in table 2.

Material	Biological Component	Other components	Summary of Manufacturing Process	Microscopy Image(s)
Bananatex[50]	Abacá banana plant stalks	Beeswax coating (not on thick sample)	- Fibre is extracted from harvested stalks and made into paper. - Fibre is spun into yarn, weaved, and coated with beeswax.	
BarkTex[34]	99% bark	Sometimes liquid lanolin, carnauba wax, shiny beeswax, and orange peel oil	- Bark cloth is harvested annually from renewable bark from the "Mutuba" fig tree. - Bark cloth is combined with a purely water-based acrylate resin.	
Hide BioTech[39]	Fish scales/ collagen	Cellulose fibre backing attached using hot-melt adhesive	- Waste fish collagen is combined with materials, including fat-liquors. - A cellulose-based fabric is attached as a backing using a hot-melt adhesive.	
Leather[55]	Cow hide	Chromium salts, vegetable matter, tanning agents, fat liquor, dye	- The hide prepared with lime, de-fleshed, and then tanned and fat liquored. - Sammying removes excess moisture. - They are sorted by grade and shaved. - Re-tanning is then used to modify the leather's properties to suit its application. - They are then dyed and finished.	
Piñatex[9]	Waste pineapple leaf fibre	42% high solid polyurethane and bio-based polyurethane	- Long fibres are extracted from plant leaves using semi-automated machines. - Fibres are washed, sun- or oven-dried and	

			purified to create pineapple leaf fibre (PALF). - PALF is mixed with polylactic acid and mechanically processed to create Piñafelt. - Rolls of Piñafelt are shipped off for finishing.	

Table 1: A table to summarise the materials tested, including Bananatex, BarkTex, Hide BioTech, Piñatex and leather materials.

Material		**Density**	**Areal Density**	**Tensile Strength**	**Seam Strength**	**Other Properties of Note**
Units		**Kg/m^3**	**g/m^2**	See individual values		See individual values
Bananatex	B100B	544.9	417.2 *(430)*	–	–	–
	B110B	637.4	491.4 *(490)*	–	–	–
	BH919	429.0	520.63 *(540)*	–	–	–
BarkTex	Mutuba 6-7 Months	272.7	349.3	–	–	–
	Mutuba 10-12 Months	235.4	199.6	–	–	–
Hide BioTech	Red	1200.7	4530.6	–	–	–
	White	950.3	1151.4	–	–	–
Leather	Ball[79]	1156.9	2399.7	*Alum-tanned: 20 MPa*	–	*Alum-tanned: Elongation at break = 50 %*
	Glove	415.7	410.14	–	–	–
Piñatex	Performance [56]	461.48 *(350)*	536.67 *(500)*	*536 N*	*301.7 N*	–

Table 2: A table to summarise the material properties of Bananatex, BarkTex, Hide BioTech, Piñatex and leather materials. Numbers in italics are taken from literature, whereas non-italic values were measured.

The number of blank spaces in tables 1 and 2 clearly indicates how few companies producing leather alternatives are willing to share testing data publicly. This initial research was conducted early in the time frame of this project, so it is possible, although unlikely, that more information is available.

These five categories of materials were selected due to their variety of appearances and main biological components. Prior to this selection, requests were made for samples from many leather alternatives companies, however, many declined to reply. This did restrict the choice of materials tested, which makes it very plausible that the optimal material for replacing leather in cricket gear has not been tested in this project. If further research was able to include materials from other classifications, such as mycelium-based materials, then that would allow for a more comprehensive assessment of the applicability of the current biomaterial market to cricket gear.

4 Methods

Given the limited amount of each material (ca. 1 A5 sheet of each material) and the variety of materials included in this investigation, a fully comprehensive assessment of the materials' properties and how they compare to leather was not feasible. It was therefore imperative to thoroughly research the application of cricket gear to ensure that the properties tested were of the utmost relevance to the final product. Experiments pertaining to the properties of the whole ball, not just the outer casing material, were identified as being outside the scope of the project, given that this would require the long and costly manufacturing of many prototypes. This narrowed scope enabled every method to undergo thorough development including preliminary testing.

To investigate the potential requirements for leather to be used in cricket, discussions were had with a large manufacturer, Gunn & Moore, and a test house, Sports Labs[58]. Ball manufacturers typically receive leather that is 4–4.5 mm thick. The drying and compression involved in the manufacturing process then reduces this to a thickness of 3–3.5 mm. This thickness is required for the ball manufacturing process, as further steps involve stitching within the material. These steps also place further restraints on any replacement material by requiring it to be just one material throughout the thickness to ensure stitching is not confined to only one layer, potentially resulting in delamination at low forces.

Sports Labs indicated that, at the material scale, several properties are evaluated, including thickness, density, 'mass per unit area', strength and elongation in tension, abrasion behaviour, water absorption, dimensional stability, and UV stability. This list inspired the testing conducted in this study. Tensile and abrasion testing were both conducted, along with measurements including thickness, density, and 'mass per unit area'. The materials' interactions with water were investigated using contact angle analysis.

Given the restrictions on resources available, and the lack of standards pertaining solely to the outer casing material on a cricket ball and the materials in cricket gloves, a large proportion of the experimental work in this project was focused on developing new and reliable testing methods. Multiple rounds of preliminary testing had to be conducted to thoroughly evaluate potential methods, with lots of iterations being tested. This was particularly true with the tensile testing method, as this was the first test completed. This meant that during the development of the tensile testing method, the materials were relatively unfamiliar, and so the iterative process took much longer than testing designed later in the project.

4.1 Tensile Testing

Since tensile testing is a general indicator of mechanical performance, a new test method was designed using Instron testing machines, informed by existing British Standards. Meyer et al.[59] conducted testing on both leather and various alternative materials and used standard tests to find the tensile strength of each material. With this testing method, the alternative materials had tensile strengths less than 25 N/mm^2 at an elongation speed of 100 mm/min; this is likely associated with a length of test of less than a minute, but the exact length of test is not given. Due to this, it was decided that a lower speed would be more appropriate so the detailed failure mechanism could be seen in the data and, therefore, investigated.

BS EN ISO 3376:2020 presents a method for tensile testing leather[60], as used by Meyer et al., with an elongation speed of 100 mm/min. Ananas Anam provides data about their main material, Piñatex[56], but here a different standard method, BS EN ISO 9073-18:2008, is used[61]. This method is the standard grab tensile test for nonwovens, involving grabbing a 100-mm-wide strip at its centre 25 mm. It was noted that a grab tensile test would be unsuitable, and the final method should aim to match the width of the test sample to the width of the grips. This is because the grab test is likely to induce stress concentrations at the edges of the grips, causing premature failure that would not indicate the true maximum strength of the materials.

This background research informed the development of a method that utilised the available Instron machines in the University of Cambridge's Department of Engineering. Force and displacement were measured at discrete time intervals using the intrinsic measurement system of the Instron machine. The displacement was also measured by a laser by recording the relative separation of two reflective strips placed at either end of the sample.

The samples were prepared with the dimensions indicated in Figure 4. The decision was made to cut samples in a dog-bone shape to induce failure in the central region and remove the risk of failure at, near, or within the grips.

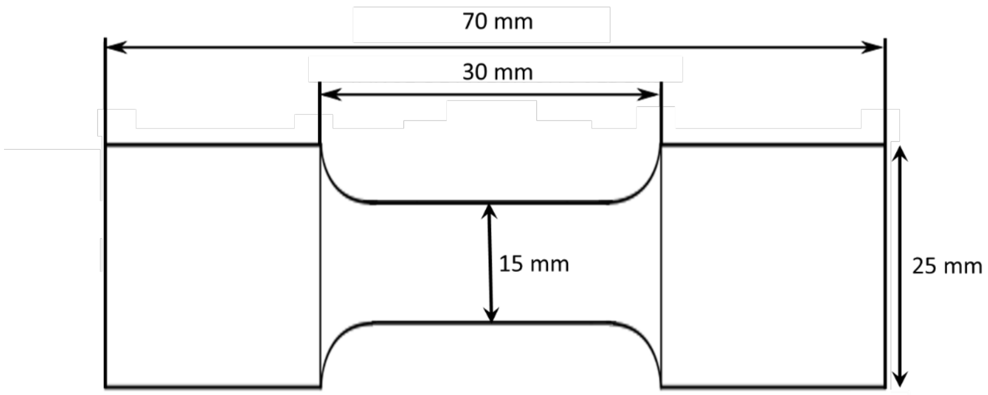


Figure 4: A diagram showing the shape and dimensions of the dog-boned tensile testing samples.

The speed of elongation was set to 10 mm/min to allow for the failure mechanisms of the materials to be seen within the data. A 2 kN load cell was used, as this was above the maximum expected failure forces for the alternative materials. When leather samples were received, this was increased to 5 kN to ensure the ball leather could be taken to failure.

Preliminary testing indicated a risk of the materials slipping out of the grips. Serrated grips were used to prevent this, but these posed a risk of catching individual fibres and inducing early failure. This was mitigated by using paper or cardboard tabs wrapped around the material sample to protect the fibrous structure. These tabs were not used on all materials as they caused smoother materials to slip.

All tests were observed, with any undesirable failure mechanisms being noted. Samples that failed at, near, or within the grips were included in the results, but any tests where the material slipped or pulled out of the grips were discounted, with repeats conducted when possible. The aim was to test six samples per material while still ensuring there was enough material remaining for other testing. The equipment outputted raw data of the force measured against extension, and this data was then processed using Excel and Python. In data processing, stress and strain were calculated using equations 1.1 and 1.2.

$$\sigma = \frac{F}{A}$$

Equation 1.1: The equation used to calculate stress, where σ is the stress, F is the force applied, and A is the cross-sectional area.

$$\varepsilon = \frac{\Delta L}{L_0}$$

Equation 1.2: The equation used to calculate strain, where ε is the strain, ΔL is the total extension, and L_0 is the original length.

Engineering stress was used, therefore assuming the cross-sectional area of the material sample remained constant, an assumption that is unlikely to hold true given the high elasticity of the materials. Engineering stress typically provides an underestimation of the stress at any given strain[62]. Here, the cross-sectional area was determined using vernier callipers to measure the thickness and width of the central section of the dog-bone. For these materials, it was difficult to accurately determine dimensions as the porosity of the materials causes them to compress under very little force. To mitigate this, the vernier callipers were tightened until they only just touched the material. Future testing could attempt to more accurately determine the cross-sectional area, for a better estimate of the stress experienced by the material.

4.2 Seam Tensile Testing

This testing method was unique and tailored to the application considered, given the significance of ‘stitchability’, which is the ability of a material to be cut and held together with stitching. Various standards describe the tensile testing of material that has been sewn together. BS EN ISO 13935-1:2014 describes testing a textile specimen that has been both frayed and seamed, with results being excluded if the failure occurs in the fabric[63]. A different testing procedure is recommended for finding the tear strength of leather, where a split down the material is torn by the free ends being pulled apart in a tensile test machine and the tear load is recorded[64]. Separate from this, BS EN ISO 23910:2019 measures the stitch tear resistance by tearing leather using a press knife[65]. None of these standard methods were applicable in this situation, as they are not appropriate for both leather and the alternative materials.

The seam tensile testing was inspired by these methods and utilised the same method as the tensile testing described previously with identical parameters. The only differences were in the sample preparation. Rectangular strips of material 25 mm wide and 70 mm long were prepared and then cut in half. This cut was then sewed together with a line of back stitch. This line of stitching ran perpendicular to the tensile load direction. The thread used was Gutermann linen thread with a thickness of 0.7 mm, following information from Gunn & Moore that indicated the thread they use is linen and 0.76 mm thick. Figure 5 shows images of one of these stitched samples.

Figure 5: Images of the seam tensile testing sample from both above and the side.

The goal was to test six samples per material, but only four were possible for the Hide BioTech Red materials as only an A5 sample of material was available.

4.3 Water Contact Angle Analysis

Contact angle analysis was conducted using the contact angle machine in the Melville Laboratory, Yusuf Hamied Department of Chemistry, University of Cambridge. Each material was loaded onto the plate in the machine, which places a single droplet of preloaded distilled water onto the material's surface. The droplet was recorded from the moment it hit the surface, and the angle between the material's surface and the drop was measured every second. An image of such a droplet is shown in Figure 6, with annotations indicating how the contact angle was measured.

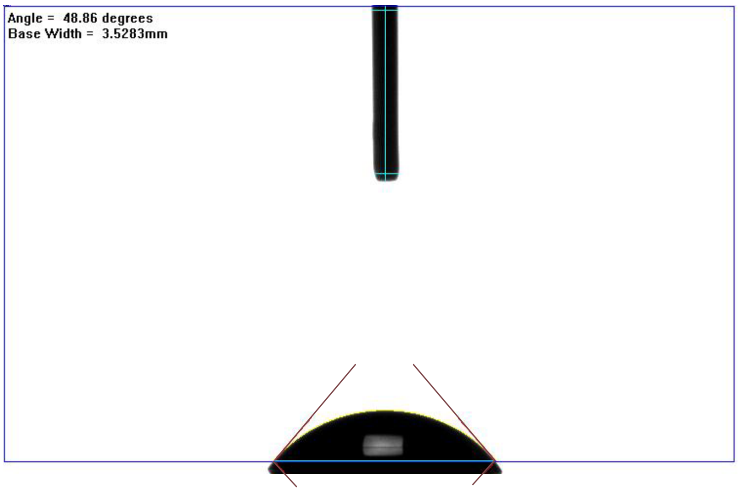


Figure 6: An image of a water droplet on the testing surface with lines indicating how the contact angle was measured.

This was repeated eight times for each material, ensuring adequate spacing between droplets to negate interference. The equipment outputted raw data of the angle measured against time, and this data was then processed using Excel and Python.

Angles greater than 90° indicate a hydrophobic material, whereas hydrophilic materials will have contact angles less than 90°[66]. Angles that decrease over time represent the absorption of water into the material. Some of the materials had uneven surfaces at the microscale, with fibres sticking out unevenly. This has the potential to interfere with the measurements if it causes the droplet to sit higher than the main surface. This was mitigated by inspecting the surface and ensuring the droplet landed on a flat area of the surface.

4.4 Abrasion testing

As indicated by Sports Labs, in industry abrasion testing is typically conducted using specialised equipment. Access to such equipment was not possible due to limits on resources; however, since abrasion was deemed to be a vital property for materials used in balls and gloves, a specialist abrasion testing rig was independently constructed.

Initial planning was focused on replicating the action of a ball being bowled, as this was thought to be the source of most abrasion during a cricket match. Upon talks with cricketers, it became apparent that the rolling of the ball on the rough ground was more likely to be a significant source of abrasion. Baum[67] mentions that one side of the ball becomes "super rough" from coming into contact with the abrasive pitch and states that the legal way to roughen the ball to facilitate swing is to use the ground. This is supported up by research conducted at the University of Sydney[68] that found a cricket ball will spend just 0.001 seconds in contact with a surface such as the pitch or bat. However, during this time, a mean force of 8.8 kN is exists between the ball and the surface. Future testing could investigate the abrasion experienced during such impacts to compare the wear rates for impact and rolling abrasion.

The rig design focused on rolling abrasion, where the sample would cover something that was undergoing roll with slip, as it would experience on a pitch, and the progressive mass lost would be measured. An initial sketch of this design, as shown in the Technical Milestone Report, is reproduced in Figure 7.

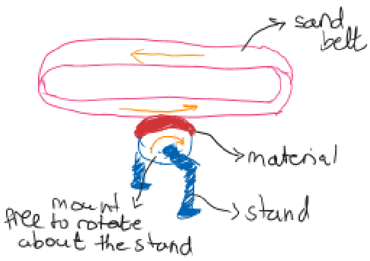


Figure 7: A rough sketch of the initial plan for an abrasion testing rig.

The final rig was comprised of a Makita 9911 handheld belt sander mounted to a bench with the sand belt facing upward. Above the sand belt, a rig was constructed that allowed a roller with the material on it to rest on a metal thread and rotate freely as the sand belt ran. Sports labs typically use H18 Taber discs[69], which are medium grit[70] , so P80 sandpaper was used in the rig. This abrasive material is attempting to replicate the abrasion experienced by a ball rolling on the cricket pitch so the lowest speed of 75 m/min was used. Future repetitions of this testing could vary the grit of the sand belt to investigate the effects of the surface roughness on the wear rate of these materials. Rough ground is known to increase wear rates as indicated by the greater swing experienced by cricketers in dry English summers[67].

This rig was designed to allow the roller itself to be removed from the thread and replaced, allowing each material to be prepped onto its own roller instead of having to remove the material each time. The main adhesives used to fix the materials on the rollers were double-sided tape. Superglue was used for the thicker materials that could not be adhered with tape alone. This rig is shown in Figure 8 and the materials used for testing in Figure 9.

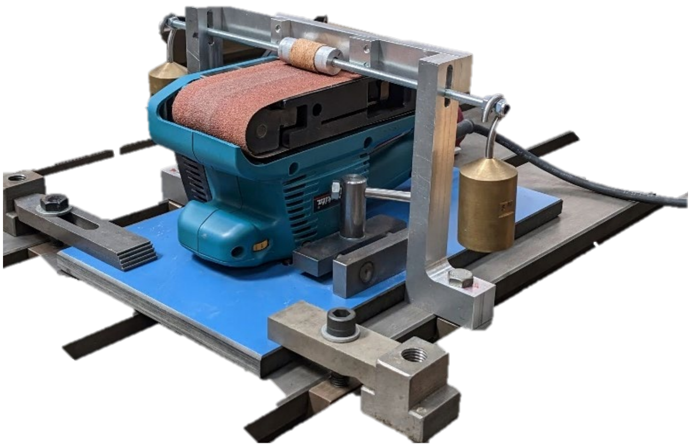


Figure 8: An image of abrasion testing the rig, using hanging weights, at a 45° angle to its frame of reference.

Figure 9: An image of the six rollers with the material adhered, pictured after the abrasion testing.

Operation of the rig required a button to be held down manually, so testing was conducted in 30-second stints, with the mass of the roller and the material being measured at every interval. Each material was abraded until less than 0.3g of material remained or until the total abrasion time reached 4 minutes, whichever came first. The original mass of material varied between material types as it depended largely on the thickness of the sample; the material sample had to be the correct length to reach around the aluminium roller. The starting masses of each material are shown in table 4.

Material	Starting Mass /g
Bananatex	0.657
BarkTex	0.743
Hide BioTech White	1.988
Hide BioTech Red	9.083
Glove Leather	0.662
Ball Leather	7.198

Table 4: The starting masses of the material samples used in abrasion testing.

The sand belt was cleaned after each 30-second interval to ensure the sand belt's abrasive properties were as consistent as possible. This was particularly imperative for the more fibrous materials, predominantly BarkTex. The cleaning was conducted using air duster cans to blow away the debris, along with the occasional use of a rough brush to loosen embedded material.

5 Results

5.1 Tensile Testing

Due to the availability of material samples, six samples were prepared for each material. If some samples failed incorrectly, it was not always possible to cut another sample due to a lack of material. This was the case for Hide BioTech in particular, where only an A5 sheet of material was available for all the tests conducted in this project. For each material, force-extension, force-extension from 5% to 100% force and stress-strain were plotted. These results have been collated below in Figure 10 and 10, with the shaded area representing the space between minimum and maximum values and the solid line representing the mean value. This has been plotted with a split axis as the ball leather was significantly stronger than any of the alternative materials and the glove leather. Evidently, none of the tested alternative biomaterials were like-for-like replacements to bovine leather for ball or glove applications. In particularly, the precise combination of strength and extensibility of bovine leather is not matched. For example, Bananatex comes close to ball leather in terms of strength, but has inadequate extensibility, whereas some leathers have comparable extensibilities in comparison to glove leather but do not have adequate strength.

Various failure mechanisms were seen in the different materials. Material samples after testing are shown in Figure 12. In Figure 12.1, it is clear how significant the elasticity of the Hide BioTech material is compared to the other samples. The failure mechanism of Bananatex seems to be dictated by a shearing force; this is likely due to the woven pattern of the fibres, which causes weakness along the diagonals. The maximum strength of the Piñatex samples were mainly dictated by the strength of the backing. As is shown in Figure 12.3, the pineapple leaf fibres remain interwoven after this backing tear, but no force was being held by them. The final failure mechanism was the significant fibre pull-out demonstrated by BarkTex. The black line indicates material that once formed a horizontal line, which illustrates how groups of fibres have pulled out and sheared to cause failure.

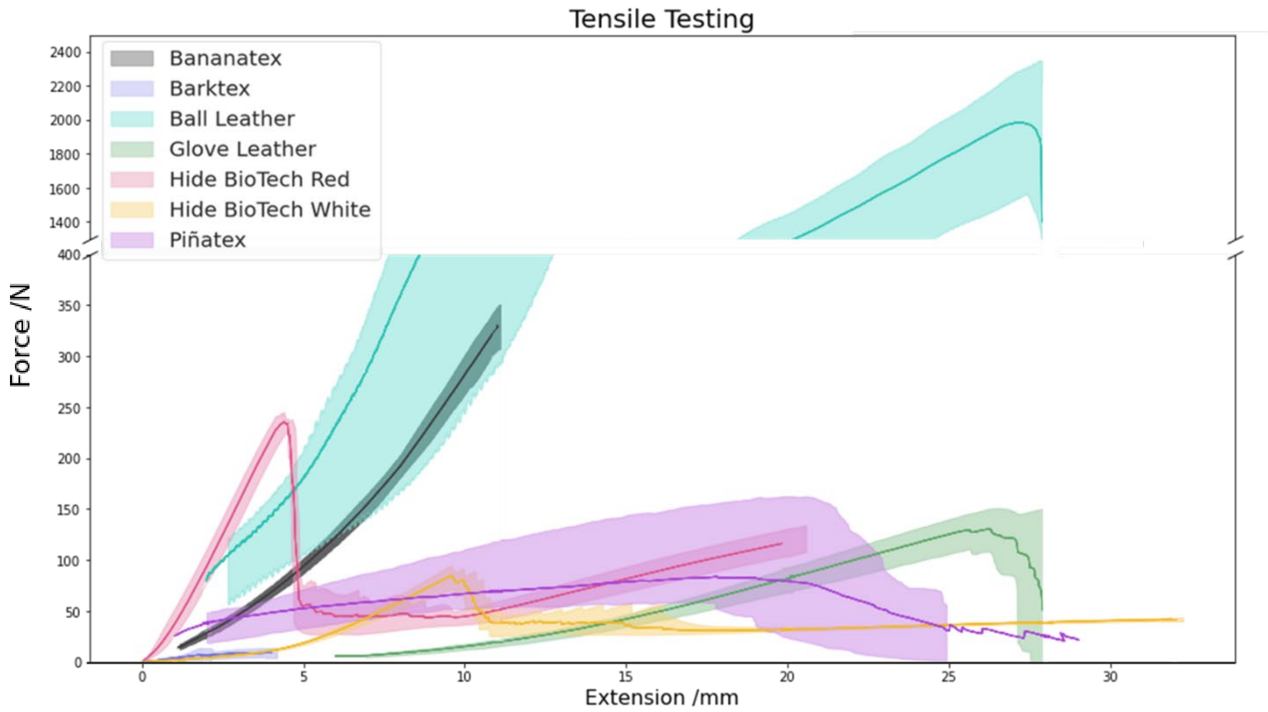


Figure 10: Force against extension curves. Data has been shown for the force range between 5% and 100% of maximum force, aside from Hide BioTech materials where the data has been plotted until the second peak.

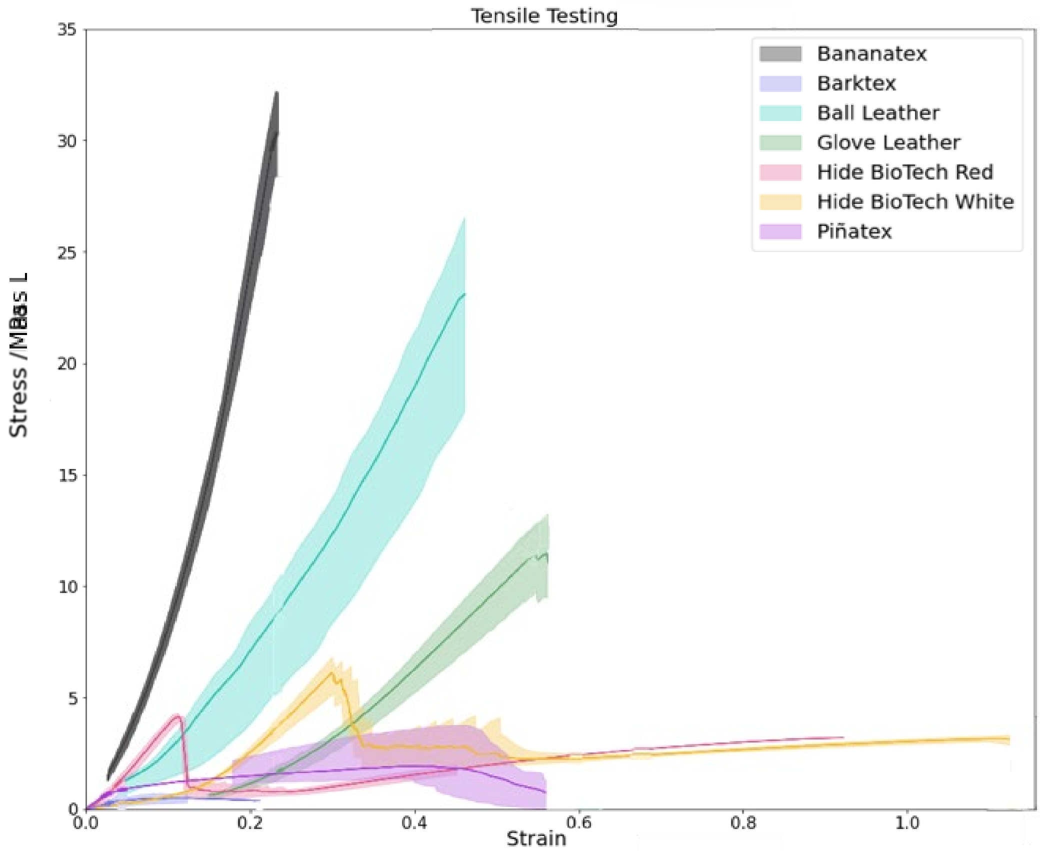


Figure 11: Stress against strain curves.

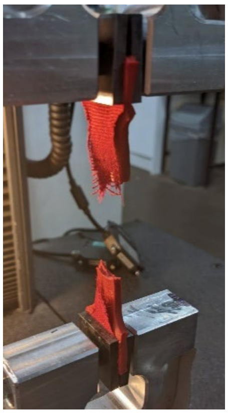


Figure 12.1: A Hide BioTech sample after failure, indicating the elongation achieved before total failure. The woven fibrous backing has snapped and then the main rubbery material has extended significantly before tearing near the change in cross-section.

Figure 12.2: A Bananatex sample after failure. The woven fibres and adhesive backing have sheared near the centre of the sample.

Figure 12.3: A Piñatex sample after failure. The backing has snapped and then the pineapple leaf fibres have pulled out from each other.

Figure 12.4: A BarkTex sample after failure. Bunches of fibres have pulled out from each other, with the failure happening near the top grip that was in motion.

5.2 Seam Tensile Testing

For each material, six seamed samples were prepared, and stress-strain curves were plotted. The ball leather was excluded from this testing as it was not possible to stitch this material without a proper leather needle and the required leather stitching skills. The results have been collated below in Figure 13, with the span between the minimum and maximum values indicated by a paler, shaded area and the mean value plotted in a darker, solid line. In all cases, the materials failed when the linen thread ripped through the sample. For Hide BioTech, it tore through the main material first and then pulled through the backing.

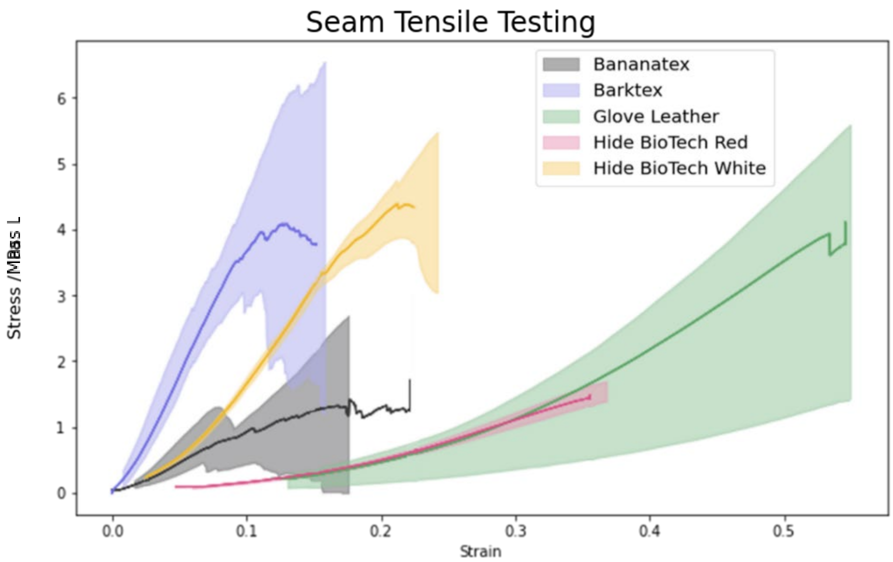


Figure 13: Stress against strain for seamed samples.

5.3 Contact Angle Analysis

The contact angle analysis was conducted early on in this investigation, with the materials that were available at the time. The test was repeated eight times for each material, with figure 14 showing the maximum, minimum, and mean angles over time from these eight tests.

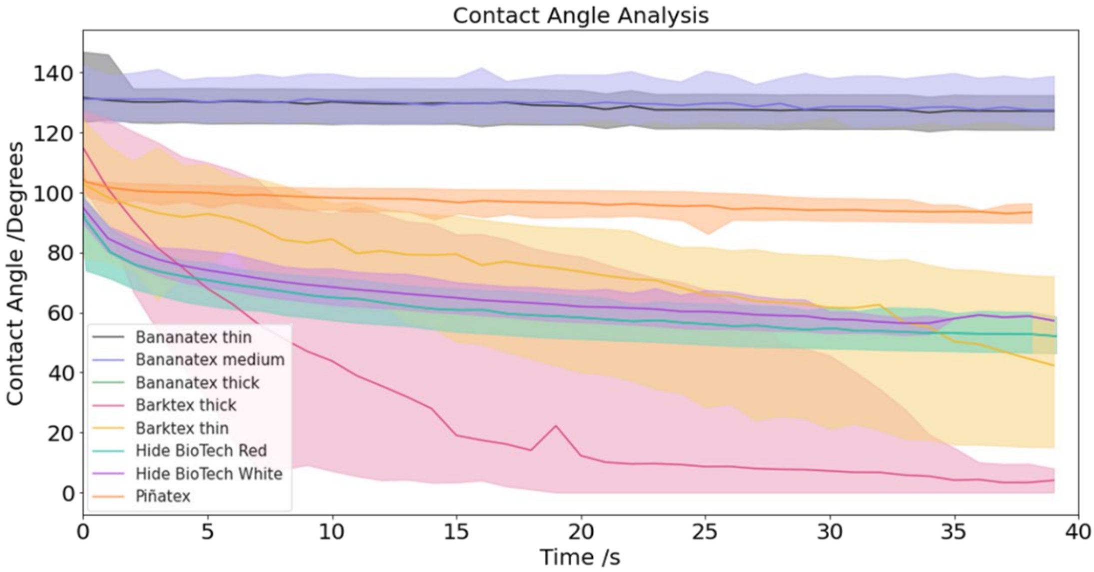


Figure 14: A plot of how the contact angle between each material and water varied over time. The shaded area represents the range between the minimum and maximum angle at each time, and the solid line indicates the mean angle at each of these times.

As figure 14 indicates, the contact angle of every material tended to settle at a final equilibrium value; these values are plotted below on figure 15 alongside error bars equal to two standard deviations.

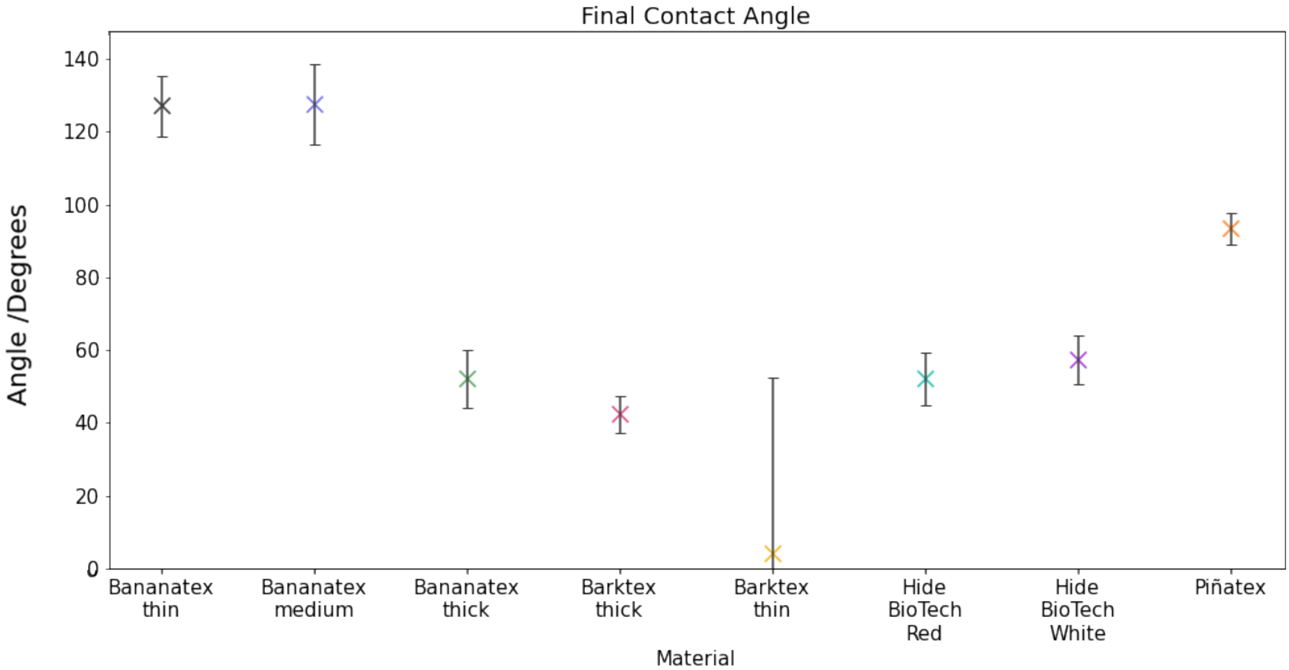


Figure 15: The final contact angle between water and each material, with the error bars indicating two standard deviations either side of the mean value.

5.4 Abrasion Testing

The mass lost over time was measured every 30 seconds and is plotted below in figure 16.1 in absolute values and in figure 16.2 in percentage values for ease of comparison.

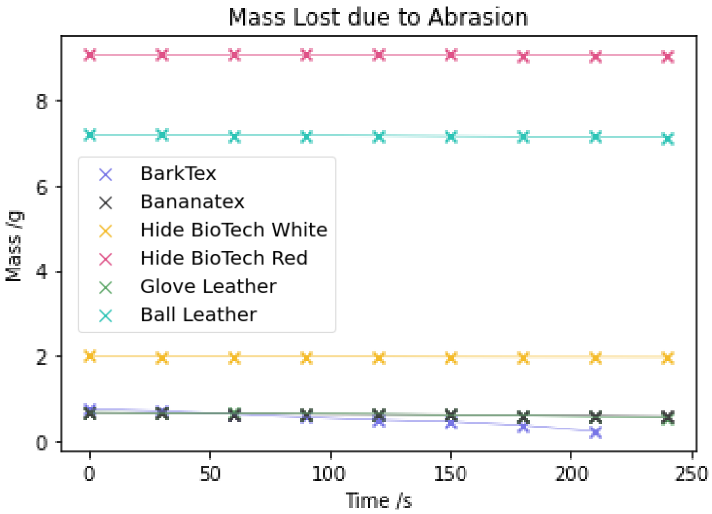


Figure 16.1: A plot of material mass over time, measured every 30 seconds for BarkTex, Bananatex, both Hide BioTech materials, and the glove and ball leather.

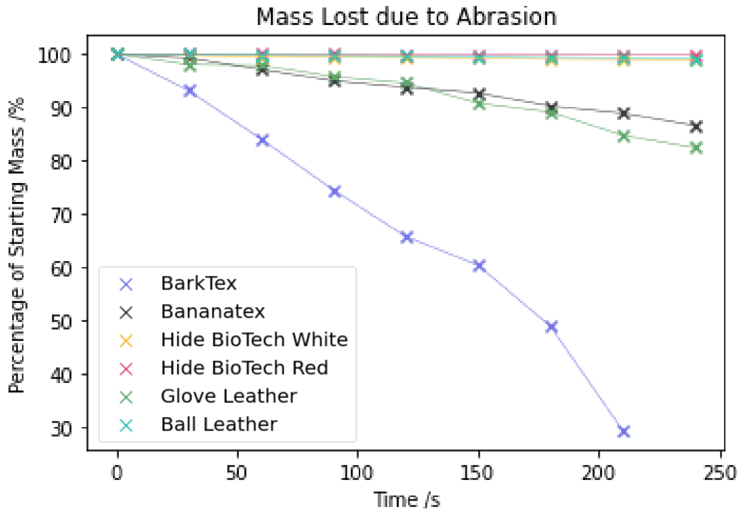


Figure 16.2: A plot of the percentage of the original mass remaining on the roller, measured every 30 seconds for BarkTex, Bananatex, both Hide BioTech materials, and the glove and ball leather.

Figure 16.2 illustrates the linearity of the rate of mass loss, the value of which is plotted in figure 17.

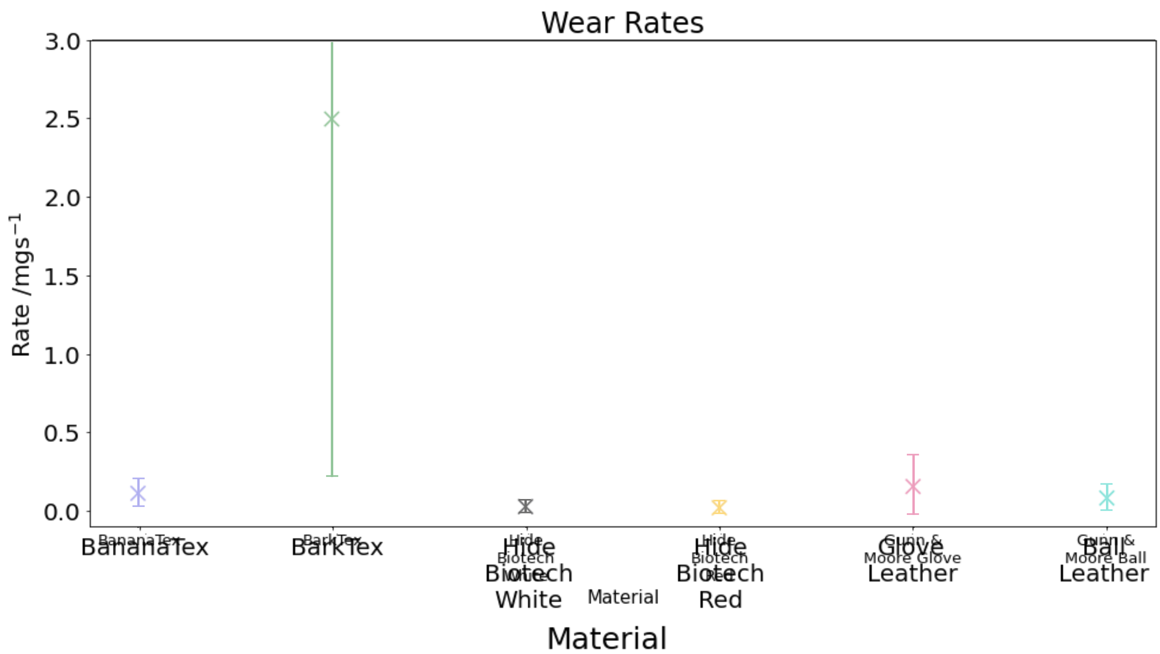


Figure 17: The rate of mass loss calculated using the data plotted in figure 16.1 for each material tested. The error bars represent two standard deviations around the mean, using individual rates calculated in separate 30 second stints.

5.5 Overall Comparisons

Tables 5 and 6 show a summary of the main values that can be taken from figures 9–17. Greyed out squares indicate values that were not tested for, as not every material could be included in every test due to both resource and time constraints.

Material	**Type**	**Mean Tensile Strength**		**Mean Apparent Modulus**		**Mean Failure Strain**	**Mean Seam Tensile Strength**	**Final Contact Angle**	**Mean Wear Rate**
		Initial	**Second***	**Initial**	**Second***				
Units		**MPa**		**MPa**			**MPa**	**°**	**mg/s**
Leather	Ball	23.1		50.2		0.461	–	–	0.083
	Glove	11.4		20.4		0.561	4.37	–	0.156
Bananatex	Thick – BH919B	–		–		–	–	52.1	–
	Medium – B110B	30.4		130.1		0.233	–	127.5	–
	Thin – B100B	–		–			1.454	127.1	0.112
BarkTex	Thick – BTM6-7	0.482		3.943		0.122	–	42.3	–
	Thin – BTM 10-12	–		–			4.118	3.99	2.50
Hide BioTech	Red	4.13	3.19	37.1	3.59	0.922	1.52	52.0	0.020
	White	6.12	3.14	20.4	1.66	1.10	4.41	57.2	0.028
Piñatex	–	1.94		4.86		0.398	–	93.3	–

Table 5: A table to summarise the mean numerical values for several important material properties for Bananatex, BarkTex, Hide BioTech, Piñatex and leather materials. Grey cells in each testing column indicate materials for which samples were not available.
**A second modulus is shown for Hide BioTech as it exhibits two clearly defined gradients, as seen in Figure 11.*

Table 5 uses mean values to represent the results of all tests for each type of material. Table 6 shows the maximum values for both tensile testing and seam tensile testing; for some materials, these maximums are much greater than the mean values. Further development of these materials should be able to reduce the variability in their tensile characteristics, potentially moving the mean value up to the maximum value stated in table 6. It is therefore important to consider both the mean and the maximum values for these tensile tests when deciding which materials to move forward with.

Material	Type	Maximum Tensile Strength		Maximum Apparent Modulus		Maximum Failure Strain	Maximum Seam Tensile Strength
		Initial	Second*	Initial	Second*		
Units		MPa		MPa		–	MPa
Leather	Ball	28.0		57.4		0.493	–
	Glove	13.4		22.1		0.585	5.61
Bananatex	Thick – BH919B	–		–		–	–
	Medium – B110B	32.2		139.4		0.241	–
	Thin – B100B	–		–		–	2.68
BarkTex	Thick – BTM6-7	0.708		7.63		0.133	–
	Thin – BTM10-12	–		–		–	6.55
Hide BioTech	Red	4.31	4.89	38.7	7.00	0.945	1.69
	White	6.82	3.39	22.8	1.21	1.20	5.49
Piñatex	–	3.78		8.18		0.567	–

Table 6: A table to summarise the maximum numerical values for several important material properties for Bananatex, BarkTex, Hide BioTech, Piñatex and leather materials. Grey cells in each testing column indicate materials for which samples were not available.
**A second modulus is shown for Hide BioTech as it exhibits two clearly defined gradients, as seen in Figure 11.*

Two apparent moduli are shown for each Hide BioTech material, due to the nature of its stress-strain characteristic, as shown in Figure 11. The first indicates the first peak, which ran from no force until the backing snapped; the second is the continued extension of the main material. This characteristic was not seen in other materials, such as Piñatex, despite their use of a primarily plastic backing that was expected to have a different tensile characteristic.

6 Conclusions

Over 100 leather alternatives are available in the market at present. Nevertheless, this study has revealed many major gaps in research on the suitability of these leather alternatives for performance applications.

There are very few scientific articles covering the material properties of sustainable leather alternatives. Additionally, as most of the companies and their materials are either in research and development stages or are being produced on a small scale, many of the firms are unwilling to share details about the material composition or the manufacturing process for IP reasons. This leads to a significant lack of publicly available research. In addition, as many of the companies are in phases of securing investment funding, they are weary of supplying samples for testing, as publication of any findings in poor light – however exploratory and preliminary - may have a negative bearing on their venture or brand.

The main conclusion is that, so far, there is no like-for-like replacement to bovine leathers used in cricket gear. A further dedicated programme of research is necessary to test, and even potentially synthesise new fully-functional leather alternatives for performance cricket gear.

The report identified the following properties as being particularly important for cricket balls: thickness, density, 'mass per unit area', strength and elongation in tension, abrasion behaviour, water absorption, dimensional stability, UV-stability, machinability (including flexibility, cutability, tear strength, ability to stitch), as well as compatibility with lacquers and compatibility with the core material. The British Standard for the cricket ball[13] places much stricter requirements on any potential replacement materials' properties. Unfortunately, these standards only specify the properties of the final ball, but it is assumed here that the sample of ball leather would be able to create a ball that abided by these standards, and therefore exact replication of this material is key. The authors found that none of the tested alternative leather biomaterials were like-for-like replacements to ball leathers. While Hide Biotech ball had the highest elongation and toughness (ability to withstand fracture) and Bananatex samples were found to be the strongest (highest force at failure) amongst the alternative leathers, their performance was not par with ball leathers. While many of the biomaterials had good abrasion resistance and water repellence (courtesy fossil-fuel based coatings applied on the bio-based materials), their seam-strength was not comparable to that of bovine leathers. Other than strength and elongation, the authors found that most of the alternatives could not be produced to the thickness (>3mm) desired for cricket balls. Hide Biotech samples were an exception, though it is understood that the process is time consuming for such large thicknesses, although this process is ideal for Hide Biotech's target sector of high-end accessories and fashion which do not require such large thicknesses. With fibrous textile-based leather samples, fraying is an issue especially from cutting. Moisture absorption is a similar challenge. Nevertheless, Hide Biotech may be suitable for practice ruberoid-like balls (e.g. in Nets or indoors).

For cricket gloves, weight (mass per unit area), water repellence, softness of leather over time, comfortable grip, tensile strength and elongation, colour fastness, pH, innocuousness and machinability (cutability, ability to stitch) are identified as important properties. Aside from material-scale testing, product-scale testing is critical. The authors found that the hydrophobicity and poor breathability of the alternative leathers presents challenges in comparison to bovine and Pittard's leather. Many of the biomaterial leather alternatives have a backing material which may also lead to sweat and moisture related issues in glove applications. Combined with its breathability, makes Bananatex the best contender for replacing the leather in gloves. From desk research, synthetic chamois leather – with existing uses in wicket-keeper gloves – has also emerged as a potential material for batting glove palms. Synthetic chamois leather can be produced from polyvinyl alcohol (fossil-fuel based), natural rubber latex, polyurethane, polyester or viscose (reconstituted plant cellulose fibre) based. These synthetic chamois leathers retain the high absorbance behaviours of real chamois leathers, can be more durable and suitable for being laundered, as well as producible in larger sizes (as the largest size of real chamois leather is limited by the size of sheep/lambs). Materials such as Pinatex may also be tailored further to produce more cricket-gear compliant materials, particularly for gloves. As many leather alternatives have been developed for footwear, where abrasion, breathability and water repellence are also important characteristics like in glove palms, it is plausible that an existing leather alternative biomaterial can be readily adapted for glove applications.

7 Recommendations for Future Work

The main recommendations of this research are as follows:

- Encourage higher level collaboration between cricket gear manufacturers, academics, and biotechnology companies to accelerate progress and reduce the current barriers of secrecy and constraints on access to resources.
- Using the benchmark values found for both ball and glove leather, experiment with materials with different biological components to assess whether these currently inaccessible materials have superior properties. Materials comprised mainly of fungus, typically mycelium[76], were identified in market research as having excellent potential for this application as they can be grown in a mesh microstructure, but were unable to be included in research due to an inability to source appropriate samples. Test a wider range of alternatives.
- Any promising materials that have been identified through testing should be subjected to life cycle assessment (LCA) to assess the sustainability implications of using them to replace leather.
- Prototyping may also reveal insights into manufacturability with some of the alternative leathers (e.g. stitching, compatibility with lacquers for cricket balls).
- The disassembly and analysis of current cricket gear will also be useful to help quantify how much material is used in various components of cricket gear. This would inform estimates of the quantity of various sustainable materials that would be required to replace these different components.
- Map process and supply chains of various biomaterial alternative leathers and explore their compatibility and feasibility for cricket gear production, in UK and globally. For example, exploration of fruit-waste based leathers could be an interesting avenue given local abundance in pomace waste.

Research in this area is currently sparse and underfunded, with literature often focusing on the application of sustainable leather alternatives in fashion and upholstery. The continual funding of research in this area, such as the ongoing Circular Cricket Gear project[12], is vital to ensuring the cricket industry is working to help decelerate climate change. The results of this research will have significant implications for other sporting industries, and widespread integration of sustainable materials across the sporting sector could vastly decrease its negative environmental impact.

While the exploration of sustainable alternative materials to bovine leathers is an important and much-needed task, particularly to fuel innovation in this sector, it is important to recognise that for truly circular cricket gear a number of other material and design aspects need consideration. For example, simply using a renewably-resourced/bio-based alternative material will not directly imply ease of disassembly or ability to be recovered/recycled – these will require careful redesign of some products. Avoiding glues and stitching may be a challenge in meeting this. In some cases (e.g. for shoes) a move towards single-material products is a route, but this is not suitable for complex cricket gear.

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