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International Conference

Smart Textiles and Emerging Technologies

Conference Proceedings 2023

Edited by: Nimesh Kankariya

Textiles and Materials Research Limited

International Conference
Smart Textiles and Emerging Technologies

Textiles that can think for themselves! This concept is very progressive, and such textiles are a fact technically conceivable today and commercially feasible tomorrow. The technology of "Smart Textiles" is an integration of almost all disciplines of applied sciences like: Textile technology, Textile chemistry, Material science, Cloth manufacturing technology, Structural mechanics, Electronics, Artificial intelligence, Biotechnology. These myriad sciences are blended with one another to produce fashionable textiles which make our lives comfortable and luxurious. SMART TEXTILES, however, are not just restricted to clothing and apparels but extend to many other applications like automobiles, robotics, aircrafts, medicine and surgery etc. The importance of these materials is so profound at some places (e.g. military battlefields) that they virtually act as lifesaving materials.

Smart Textiles and Emerging Technologies (STET) International conference was aimed to provide a platform for the exchange between the academic researchers, and industrial experts in the area of smart textile materials and technologies.

STET-2023 was a remarkable success. Academic and industry professionals, research students (Ph.D. and Mater Students) from number of countries have registered to participate in this two-day virtual conference. Advances in the smart textile sector through presentations from research experts and change-makers in the industry were highlighted in this conference. This event was an all-encompassing smart textile materials and emerging technology event.

International Conference - Smart Textiles and Emerging Technologies

Conference Proceedings – 2023

Edited by
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Nimesh Kankariya serves as Director for Textiles and Materials Research Limited, New Zealand (TexMat Research). Much of his recent research focuses on smart textiles, including compression textiles and emerging technologies. He has been involved in several industrial-based research projects. Nimesh's doctoral thesis "Textiles and Compression of the Lower Limb" is on the Sciences Divisional list of Exceptional Doctoral Theses, University of Otago, New Zealand.

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Adaptive building of truss network for deformation analysis of 3D-knitted technical-textiles

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Abstract

Modern weft knitting machines with individual selection of the needles and advanced take off systems for the ready structure provide large options for production of seamless 3D knitted textiles for technical, medical, and clothing applications. While the hardware allows building of such structures, there missing CAD design tools for development of the knitting code. The absence of suitable software is caused by few reasons: first, the hardware with the knitting machines is relatively new and the textile industry is conservative and do not change the equipment quickly. Second, the technical design of 3D products requires the programming skills of software developers, who need to have textile knowledge as well. Last but not least, the market for such software is very narrow and potential investors are often not ready to support development of such complex engineering products. This paper presents a method for analysis of the deformation of 3D knitted structures, using commercially available software with additional custom scripts developed by the authors.

Keywords: Flat knitting, Adaptive remeshing, Fabric deformations, Virtual avatars, FEM

1 Introduction

The presented method focuses on flat knitting as a specific application field and aims to represent distortions in knitted textiles on moving virtual avatars. However, it should be emphasized that the presented method also has potential for Finite-Element-Method (FEM) computation of other textile materials. By using a Hybrid-Graph-Mesh (HGM) oriented to the geometry of a Non-Uniform Rational B-Splines (NURBS) surface (Figure 1), a high homogeneity of edge lengths and a high approximation accuracy and continuity of the subsequent computational mesh (FEM) are achieved. The structure of this HGM will be described later under the heading Hybrid-Graph-(Re-) meshing. This proposed method can be classified as adaptive remeshing, allowing for adjustment of element size and shape at specific locations in the mesh. This Method was mentioned in a previous publication of Franz Dietrich about Warpage-Simulation in so called KNIT-MESHES (Dietrich 2023). Refinement of the network structure is achieved through the placement and connection of Steiner-Points along orthogonal trajectories of an input geometry. The Steiner-Points used are derived from geodesics (Figure 1) or iso-curves on an input surface, here NURBS. In the course of the paper the procedure will be described in more detail. The term and use of so-called Steiner points is introduced under the heading Continuities and Network Construction Methods.

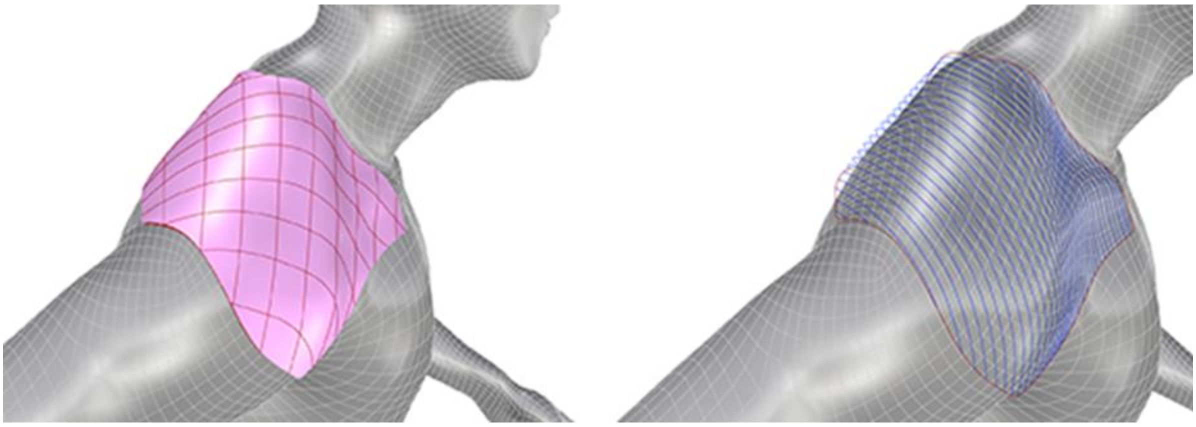

Figure 1 Initial NURBS-Surface (left) and derived Geodesic-Curves(right)

To evaluate an initial prototypical kinetic FEM simulation, color-scales (Figure 7) are used to represent length changes in the beam-segments and trusses of a computational mesh (Figure 6). The method has the potential to improve the representation of distortions in knitted as well as woven textiles on moving virtual avatars. Further evaluation and refinement measures are required to validate the performance of the method and optimize its computational foundations. In the current prototypes, beam segments are stiffened and do not generate bending moments or shear forces in the structure. The fundamentals of the kinetic method with reference to the use of truss elements were also presented in the mentioned paper above "simulation method to predict the shape-fidelity of 3D-knitted-textiles" (Dietrich 2023).

2 Continuities and network construction methods

The authors note that the comprehensive investigation of continuous development algorithms for creating discrete grids or polygon meshes in various application areas is an important part of the development of textile FEM methods, which are in turn a subfield of the FEM applied in continuum mechanics (Daniel 2015). In particular, we see a high importance in achieving a largely C1-continuous continuity and consistency of edge lengths of truss elements (C1 elements) for better textile finite element analysis or higher realism approximation in the results for textile materials or knitted fabric with homogeneous, not changing loop-relations (Figure 2). Although C1-continuity sometimes requires additional nodes in the model, it can lead to the mentioned improved and more accurate calculations, according to Lesicar et al. (2012). The additional required nodes are referred to as Steiner-Points in the method described here (hybrid-graph-mesh). Steiner-Points form a part of specific network construction strategies, especially in triangulation. They are used here, for example, to address problems with twisted or inconsistent edges (Frey et al. 2000). The historical development of network construction methods, including Delaunay triangulation, the Doo-Sabin method, ear clipping, the Bower-Watson method, and the Chew algorithm, illustrate the ongoing adaptation of network qualities or network strategies to specific contexts. We utilize existing nomenclatures and classifications to reduce new terminology categories. Overall, we deduce that textile FEM computational networks also pose special requirements that can be complemented by known solutions and expanded by new concepts described here.

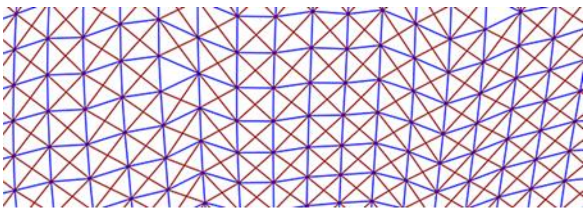

Figure 2 Relative homogeneity in size (blue) & continuity at the transition of the truss-elements in KNIT-MESHES (red)

In the proposed method, the specific requirements related to flat knitting products and other textile materials take centre stage. In these areas, complex geometries, and requirements (mesh ratios, knitting patterns, yarn selection) necessitate robust adaptability to material properties and precise representation of surface deformations. We emphasize the importance of specific adaptive remeshing techniques, including the later introduced hybrid-graph-remeshing, to enhance accuracy and efficiency while considering high C1 continuity in numerical textile simulations.

The concept of hybrid-graph-remeshing is based on placing network construction nodes at control points and/or additional algorithmically generated nodes (Steiner-Points) on an underlying surface geometry (NURBS, point-cloud, polygon-mesh) as seen in Figure 3. Geodesic curves, Gabriel-Graphs, and Steiner-Points can be utilized as strategies to refine and improve the resulting network structures.

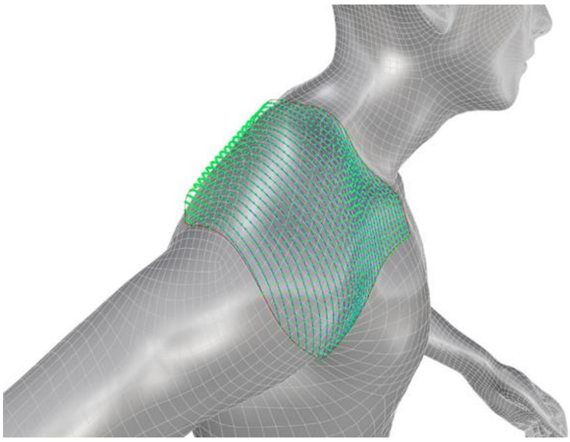

Figure 3 Steiner-points on geodesic-curves derived from initial NURBS-surface

The aforementioned hybrid-graph-mesh construction concepts pave the way for the subsequent exploration of a kinetic FEM methodology for representing fabric deformations on moving virtual avatars, with particular consideration given to the challenges associated with knitted textiles. The overall FEM approach emphasizes the importance of high C1 continuity in trusses and beam elements of the algorithmic derivation for seamless 3D construction of polygon meshes (KNIT-MESHES) (Dietrich 2023) to simulate and visualize fabric deformations more accurately on complex doubly curved and animated geometries.

The prototypical FEM method presented at the end of the paper refers to the challenges outlined in a paper by the authors Muenks et al. (2023). The evaluation concepts demonstrated here in the form of coloured representations and scales can help identify areas with significant distortions in specific motion poses, represented by frames of a 4D scan.

3 Hybrid-Graph-(Re-) meshing

As discussed above, various historical concepts and conditions can be employed to achieve improved edge length consistency and high approximation through remeshing techniques. Some of these include geometry adaptation, such as the use of adaptive remeshing techniques that conform to local geometry. These techniques enable efficient generation of quad-dominant meshes where quadrilaterals are the predominant elements. Additionally, smoothing techniques can be applied to convert triangles into quads, thus increasing quad dominance. Another approach is to employ anisotropic refinement to achieve a higher concentration of quads in areas with complex geometries or high accuracy requirements (Frey et al. 2000). These mesh generation and refinement techniques play a crucial role in constructing the stiffness matrix for the FEM. By considering constitutive features during mesh construction, more accurate modelling and simulation of physical problems can be achieved.

In the method presented here, to approximate a mesh (or graph, Figure 4) to a B-spline or NURBS surface, the placement of "mesh construction nodes" at a) the control points of the surface, b) set points on the surface, or c) control or Steiner points aligned on an iso-curve of the surface.

In this case, it is an isotropic mesh construction or isotropic mesh refinement. The elements remain relatively constant in size throughout the mesh, regardless of the local curvatures or other characteristics of the structure. The adjustment of the elements occurs uniformly in all directions, without specific scaling or alignment with respect to certain features of the problem. Refinement is achieved by reducing quad elements and using triangles while maintaining overall element size.

This creates an approximation between the constructed polygon mesh or graph and the underlying surface (NURBS or mesh) dependent on element size. This construction strategy bypasses the specificity of given polygon meshes in favour of a relatively homogeneous computational graph or mesh. Since a NURBS surface is continuous, every point on its given surface (UV domain) can be determined. Added Steiner-Points lie precisely on the approximated surface within a given tolerance, ensuring the best possible approximation to the input surface. In this context, the optimization of algorithms for automatic creation of NURBS surfaces based on point clouds is a currently important research field.

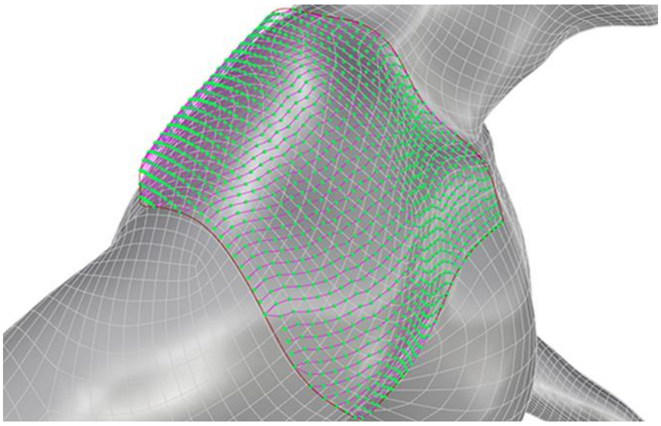

Figure 4 Graph (aka orthogonal trajectories) interpolated by grouped Steiner-Points derived from Geodesics-Curves or Iso-Curves on NURBS surface.

4 Geodesic UV curves

The first constitutive requirement is a set of asymptotically parallel curves on the approximated NURBS surface. These are also referred to as geodesics (Figure 3), although they do not necessarily describe the shortest path. They serve as the basis for constructing the later orthogonal trajectories (Figure 4) for the hybrid- graph-mesh (Figure 5) to be created. Orthogonality is an important requirement in this context to enable the representation of woven as well as knitted structures.

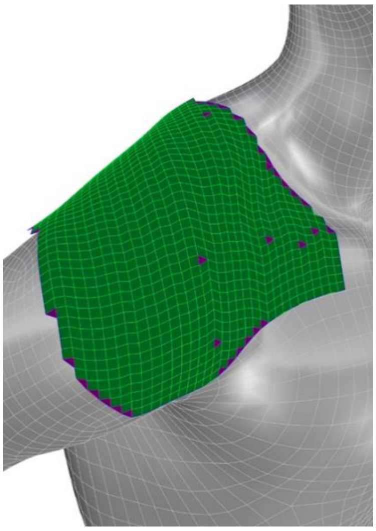

Figure 5 Hybrid-graph-mesh from lofted graph-segments

Various approaches exist for generating geodesics on a NURBS surface. However, it should be noted that geodesics do not necessarily run in parallel, and the choice of the method for geodesic generation depends on the specific geometry. Although the focus of this work is not on computation of geodesics, the following standard tools available in the software Rhinoceros 3D are worth mentioning:

- Extraction of parallel isocurves,
- UV based interpolations based on isocurves,
- Parallel projections using normal vectors,
- Contour lines in any direction on the surface, and
- Heat map or vector field-based methods.

In addition, using the scripting interface of Grasshopper (Iron Python, C#), geodesic graphs can be generated using point-clouds on the surface or through shortest path algorithms. The use of vector fields or other derived quantities (derivatives) is possible.

5 Orthogonal trajectories

After constructing all geodesic curves, they are processed pairwise in a loop. The entire list is partitioned pairwise, with each iteration processing i+1. Both curve lengths are divided by a divisor, which can correspond to a) the geodesic distance or b) any arbitrary divisor. This division determines the point spacing of the Steiner-Points on the geodesic curves or given Surface. This means that for each pair of geodesics (G_i, $G_{\{i+1\}}$), a set of points P is defined, where each point P_j in G_i and $G_{\{i+1\}}$ is calculated by the formula P_j= Length G_i / Divisor and P_j= Length ($G_{\{i+1\}}$) / Divisor.

These points $P_{i,j}$ and $P_{i+1,k}$ are then connected to generate the orthogonal trajectories of the hybrid graph mesh. The result is a relatively homogeneous quad-dominant graph over the input geometry (NURBS surface) in terms of its edge lengths. The term "hybrid-graph" derives from the hybrid use of representation and model construction concepts for continuous geometry (NURBS) in combination with mesh construction strategies for discrete geometries suitable for FEM computation.

The described concept provides the foundation for further refinements or allows for additional implementation of other conditions to follow a remeshing process based on desired properties. In the publication mentioned above, the co-author of this study, Franz Dietrich, describes possible concepts for the kinematic FEM method with reference to similarly structured polygon meshes or graphs (Dietrich 2023). In addition to describing the computational method for FEM analysis, further references to publications by other scientists, such as Popescu (2019) and

Eschenbach (2020), are provided regarding the described mesh construction concept of quad-dominant polygon meshes with high edge length homogeneity.

The additional conditions mentioned in the above paragraph regarding remeshing concepts could, for example, involve the selection of certain graph lines with undesired angular results. It is conceivable that a mesh refinement algorithm could identify critical angles beyond a threshold and place new Steiner-Points to avoid the critical angle. Results of such refinements could lead to an improvement in the continuity (C1) of the FEM computation networks (Figure 6) at the element boundaries.

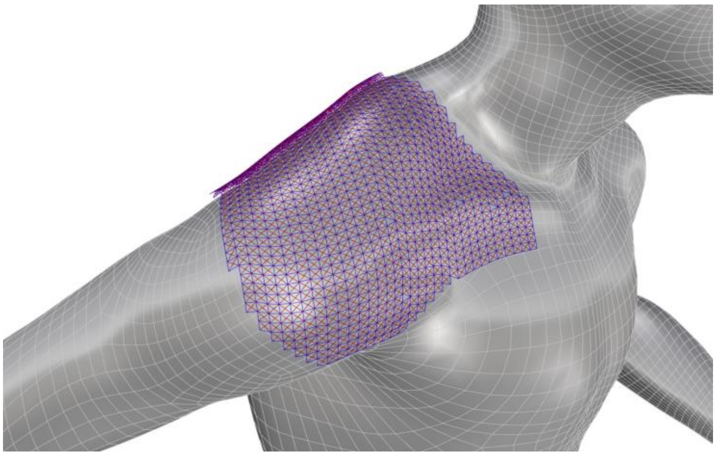

Figure 6 Later stiffend beams & trusses from Hybrid-Graph-Mesh

However, the methodology described here would need to be evaluated based on measurement series compared with analog sample examples. In this context, suitable measurement methods or devices need to be verified for sufficient correlation with the calculation results. Subsequently, refinement solutions for higher continuity could be designed.

6 Prototypical setup FEM method

In the prototypical algorithm presented on the following pages for textile FEM computations, the edges of the quads and triangles in the hybrid graph mesh are used as length flexible and stiffened beams acting like trusses in a kinetic FEM calculation. The evaluation is based on the relative elongation or compression in percentage. The beams in the initial model state (Frame 0) are compared with the bars in any subsequent model state (Frame x) over time (t). The initial lengths (L1) are divided by the lengths of the deformed beams/trusses in Frame x (L2) to obtain a positive or negative value. The absolute value is used to represent overextended or compressed areas on two colour-scales (Figure 7). One scale visualizes all stretched and the other all compressed or contracted beam/carrier elements. Furthermore, the changes of the lengths are indicated in percent.

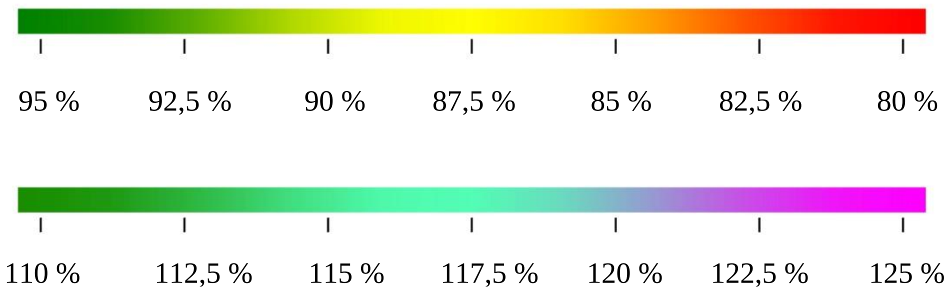

Figure 7 Colour-scales with shrinkage and strain in percent

Additionally, features related to stress could be considered, such as absolute or relative elongation combined with multiplication of the modulus of elasticity. This allows for the representation of stress using a colour scale. However, in the current implementation, these features are not present.

We have opted for a hybrid truss/beam model as it appears to be suitable for textile computations compared to a spring model. The hybrid model can capture the specific characteristics of textile structures, such as relative elongation and stress, more realistically. Springs would overestimate the deformability of textiles according to our current assumptions and lead to inaccurate results. An extension of the hybrid model allows for the modelling of bending moments and shear forces in the structure, as well as compression and contact forces, which can contribute to a more realistic representation of textile structures (Kyosev 2005 and 2019). As mentioned earlier, the beam elements are currently treated as trusses but will be used as beams in later optimizations.

The next page shows the length changes as coloured beams instead trusses from the FEM calculation of a motion study with 9 frames (Figure 8). The frames are shown arranged in a grid. Clear length changes in critical areas are visualized in a comprehensible way. The simulated virtual textile section is held at its element boundaries (naked edge) during the calculation. Thus, the curvature properties and changed surfaces of the collision model (avatar) are transferred to the textile piece. Surface friction or adhesion between simulated textile and avatar is not considered. Both surfaces collide in a sliding manner.

Conclusion and recommendations

In conclusion, our research underscores the importance of advancing computational foundations and conducting benchmarking studies in the field of three-dimensional knitted textile FEM computations. These efforts are essential for improving the accuracy and reliability of simulations in knitted textile engineering and design.

Further in-depth investigations into the computational foundations of the prototypical "Rhinoceros 3D/Grasshopper/Python" FEM calculation setup are needed, along with continuous advancements in network (mesh) construction algorithms tailored to flat knitting and textile applications. These advancements lay the foundation for future research and development efforts aimed at achieving a more accurate representation of fabric behaviour on virtual avatars.

In the context of evaluating measurement methods for assessing force ratios in physical knitted samples, it is crucial to consider a range of techniques, such as mechanical and optical strain measurement, image processing, and strain sensors. Additionally, exploring the potential of transferring measurement data as matrices, with attention to node density relative to sample size, has the potential to streamline stress calculations based on modulus of elasticity values. These steps are essential for advancing our understanding of force assessment in knitted samples.

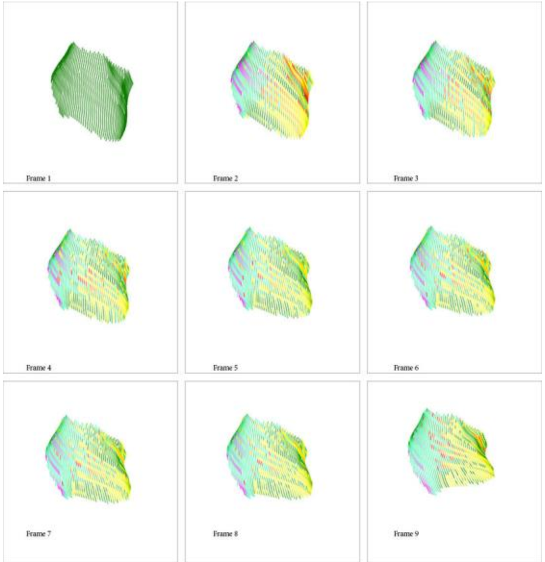

Figure 8 Frames from Motion, showing lentgh changes in Beams (stiffend) and Trusses after Collision with Avatar

Roles of author

Study Conception and Design (F.D.); Experimentation – Collection of data (F.D.); Analysis and Interpretation of Results (F.D., Y.K.); Writing the Original Draft (F.D.); Writing-review and Editing (F.D.); Over all supervision (Y.K.).

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Conflict of interest

The author declares that there is/are no conflicts of interest.

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Impact of 3D printing/modelling on avant-garde fashion

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Abstract

The fashion industry works on its theories, i.e., Trickle Up, Trickle Down and Mass Dissemination. These theories consisting of various types of fashion, once they revolutionised the fashion industry, are now considered as "Traditional methods" of the fashion businesses due to the 3D printing/modelling methods. Avant-garde is one of them, defined as experimental, unorthodox or radical. This fashion is once considered beyond the imagination of ordinary people, the experimental designs, that anyone ever wears. It is the reflection of forward thinking and progressiveness. The base of future design, artistic imagination, and the revolution in art, culture, and society was built upon the worldwide prodigal sensation "avant-garde".

With the new advancements in materials and technology, 3D printing/modelling has grabbed the attention of fashionistas. It creates 3D objects by dozing sequential layers of various materials. Many brands have adopted this technology to transform by experimenting more comprehensive range of applications. According to the ISO/ASTM 52900:2015, It is the geometrical representation by supplement manufacturing to create physical objects by consecutive adds of materials with controlled thickness, operated by the software. It is opposite to conventional manufacturing technology. It is now widely popular for prototype development and the production of various objects. This technology has captured the various trims and materials with autogenerated shapes, which was the base of playing the theatrical artwork of avant-garde. 3D printing/modelling may be considered a threat to such creative experiments with the materials. The study analyses the impact of 3D printing/ modelling on avant-garde fashion style in the fashion industry. The study is qualitative and exploratory, where recent advancements in 3D printing/ modelling have been studied and compiled to address the issue. Valid references have been considered for the discussion.

Keywords: 3D Printing, 3D Modelling, Avant-garde, Fashion

1 Introduction

The intersection of fashion and technology has given rise to a field that explores the innovative and creative fusion of fashion and technological advancements to create new possibilities in the field of design. From high-performance fabrics with moisture-wicking properties to fabrics with embedded sensors and LEDs, technology has led to the creation of materials that go beyond traditional aesthetics and offer enhanced functionalities. Computer-aided design (CAD) software revolutionized fashion design by providing scope to the designers to create digital prototypes of garments (Torán, Bonillo, and Espí 2018). This accelerates the design process and enables precise visualization before physical production. Computerized knitting machines, laser cutting, and 3D printing have enabled more efficient and customized manufacturing processes, reduced waste and allowed for intricate designs. The development of smart textiles, which integrate electronics and technology directly into fabrics, has resulted in wearable technology. The rise of e-commerce and digital retail has changed how consumers interact with fashion. Online shopping platforms, virtual try-ons, and augmented reality (AR) shopping experiences are changing the way consumers discover and purchase fashion items. Livestreaming, virtual reality (VR), and interactive presentations allow designers to engage global audiences in new and immersive ways. The advancements of fashion and technology evolve new avenues for creative expression and production efficiency with sustainability and consumer aspects.

Fashion is influenced by a variety of factors, including societal norms, cultural influences, historical context, economic conditions, and individual preferences. It can be categorized into different ways, such as classic, casual, formal, streetwear and many more. It reflects broader cultural values and social dynamics. Avant-garde is closely related to fashion but distinct concepts within the realm of clothing and style. Intelligencers, critics, and scholars frequently employ the word avant-garde when interpreting, critiquing, and analysing art, architecture, armature, film, and fashion (Akcan 2002). Still, the meaning of the term avant-garde is frequently nebulous. The characteristics used to determine if an artist or developer of their work is Avant-Garde are frequently not harmonious among the intelligencers, critics, and scholars assaying their work, these characteristics constantly change from time to time and differ among disciplines which reflect the constantly shifting and social construction of meaning in different surrounds. The term Avant-garde is continuously mooted about in magazines, journals and fashion-show reviews making it delicate to conceptualize (Higgins 1970).

When 3D printing technology enters the retail assiduity, 3D manufactured shoes, jewellery, consumer goods and apparel are emerging into the request. The combination of fashion and 3D printing may not feel like the most natural fit, but it's starting to become an everyday reality. For case, big companies like Nike, New Balance and Adidas are seeking to develop the mass product of 3D manufactured shoes. Currently, 3D-published shoes are produced for athlete's shoes, custom-made shoes and sneakers. The advantages of explorations of materials with 3D printing are vast and open to achieving the ideas of avant-garde designers. The objective of the study is to propose an overview of the impact of 3D printing on avant-garde fashion. The study is exploratory and theoretical in nature. Attributes, definitions, methods and techniques of 3D printing and avant-garde are summarized along with the process to create a base to analyse the relation of both and future scope in the industry.

2 Impact of 3D printing on avant-garde fashion

2.1 Avant-garde fashion

Avant-garde fashion refers to a style or movement within the fashion assiduity that's characterized by its innovative, experimental, and frequently unconventional approaches to design, accoutrements, and aesthetics (Gongini 2023). The term "avant-garde" first comes from the art world and is used to describe artists and movements that are ahead of their time, pushing the boundaries of traditional cultural morals. Also, in the environment of fashion avant-garde contrivers strive to challenge and disrupt established morals, traditions and prospectus. Avant-garde fashion is not concerned with mass-request appeal and marketable viability but rather focuses on cultural expression, pushing the limits of creativity, and frequently blurring the line between fashion and art (Best, and Burns 2013).

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2.1.1 Attributes, methods and techniques of avant-garde

Figure 1 Attributes of avant-garde fashion

Distinctive characteristics of avant-garde fashion include experiment, cultural and social commentary, innovation, unconventionality, artistic expressions, limited production followed by collaboration. Avant-garde fashion designers are known for their experimentation with unconventional materials, forms, silhouettes, and techniques. Designers adopt new technologies and integrate them into their creations. These concepts challenge traditional ideas of beauty, gender, and practicality. This type of fashion may feature uneven designs, extreme proportions, and clothing that may not be ideal for everyday wear thus resulting in thought-provoking and visually striking pieces. This fashion is often seen as wearable art, requiring partnerships with artists, craftsmen, architects, and technologists to bring intricate and original designs to life. The avant-garde fashion style blurs the line between fashion, art, and design, resulting in unique and artistic creations. These pieces can be showcased in galleries or fashion shows to highlight their artistic nature (Cholachatpinyo, Fletcher, Padgett, and Crocker 2002).

To sum it up, avant-garde fashion is all about creativity and pushing boundaries in clothing design. It defies conventional norms, embraces innovation, experimentation, and artistic expression, and is a thrilling and influential aspect of the fashion world.

The avant-garde fashion movement focuses on embracing innovation, challenging traditional norms, and pushing the boundaries of design and creativity. Designers aim to challenge conventional norms, stimulate contemplation, and communicate a distinct message through their creations. Designers who are considered avant-garde often explore innovative methods of utilizing materials, textures, and techniques in their creations. They may incorporate newly invented fabric structures, combine unexpected materials, or incorporate advanced technologies like 3D printing, laser cutting, or smart textiles to achieve their desired outcomes. Avant-garde fashion is known for its inventive and unconventional designs. Designers frequently craft clothing with distinct shapes, asymmetrical lines, exaggerated proportions, and intricate details. The aim is to produce visually stunning and thought-provoking pieces that defy the conventions of traditional fashion. The avant-garde fashion industry places great importance on the quality of its products, focusing on intricate details and skilled craftsmanship. Each garment is carefully made in limited quantities to ensure its excellence. Artisanal techniques are highly valued by avant-garde designers, who often collaborate with talented craftsmen. Fashion pieces that fall under the avant-garde category are usually made in limited quantities. This makes them exclusive and highly sought after by collectors and enthusiasts. The production process for these pieces often involves small ateliers, artisanal workshops, or even the designer's studio, rather than large-scale factories. Fashion designers often showcase their avant-garde creations in fashion shows or exhibitions. These events offer a platform for them to present their work to the world. These shows can take place during fashion weeks, art events or specialized avant-garde showcases. The presentation itself can be a work of art, with designers incorporating theatrical elements, unusual runway settings, or multimedia displays to enhance the overall experience. Avant-garde fashion often entails working with other artists, craftsmen, architects, and technologists to bring the designer's vision to life. These collaborators bring their expertise to the table, resulting in multidisciplinary and innovative creations that push boundaries. Although avant-garde fashion may not be as popular as mainstream fashion, its influence goes beyond the runway. Avant-garde designs often inspire new ideas and push the industry to evolve in other areas of fashion, art, and design. Avant-garde fashion is a blend of art and clothing that prioritizes creativity, experimentation, and pushing the boundaries of conventional fashion. It challenges traditional ideas, welcomes unconventionality, and endeavours to stimulate thought and emotions with its innovative designs (Seyed, and Tang 2019).

To create avant-garde fashion, a blend of traditional and modern tools and techniques is necessary. Designers in this field usually challenge the limits of artistry and skill, utilizing an array of methods to materialize their groundbreaking ideas. Below are some of the commonly employed tools and techniques for creating avant-garde fashion:

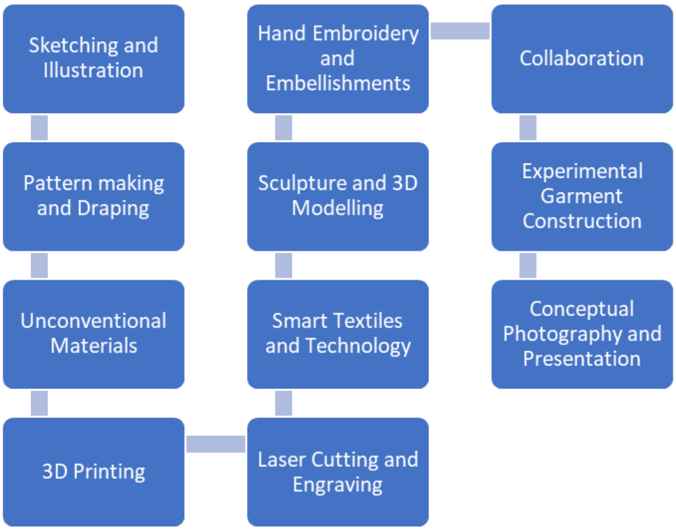

Figure 2 Process of creating avant-garde fashion

The process of creating avant-garde fashion starts with sketching and illustrations, where designers visualize their ideas by drawing techniques on paper or digitally with the help of software. These concepts are converted into unique silhouettes by pattern-making and draping. Pattern making involves making templates based on a designer's sketches and draping involves manipulating fabric on a dress form to create three-dimensional shapes. Avant-garde designers often utilize unusual materials like plastics, metals, leather, non-traditional fabrics, and even found items to create their unique clothing pieces. They may also mix and match materials to create innovative textures and structures. The technology of 3D printing enables designers to create intricate and complex shapes that would be difficult to achieve through traditional methods. It is frequently used to manufacture accessories, jewellery, and even entire clothing items with intricate details and shapes. Laser cutting and engraving are applied to fabrics and materials to achieve precise cuts and manipulations, with this method, designers can add intricate patterns, textures, and details to their garments and accessories. Innovative designers frequently fuse technology with their designs, such as embedding LED lights, sensors, and interactive features that react to motion or touch. This blurs the boundary between fashion and technology. Materials such as wire, foam, and other sculpting materials to construct intricate shapes are incorporated along with unique seams, closures, and fastenings to create innovative garments with a striking appearance. These avant-garde pieces are presented and published with visually stunning images and videos with the team photographers, stylists, and art directors to embody the essence of their designs (Seyed, Devine et al. 2021).

The creation of avant-garde fashion involves various tools and techniques that reflect the experimental and boundary-pushing nature of this style. Designers pull inspiration from various disciplines to bring their creative visions to life in the form of wearable works of art.

2.2 3D printing

The process of creating three-dimensional objects by adding material layer by layer is called 3D printing or additive manufacturing. This technology is widely used in industries such as manufacturing, healthcare, automotive, aerospace, and fashion.

3D Printing offers several advantages. The technology of 3D printing makes it possible to create intricate shapes and designs that would be difficult to produce through conventional manufacturing techniques. The product development process can be accelerated by quickly producing and testing design iterations. Customizing objects to fit personal needs or requirements is a simple process. 3D printing is different from traditional subtractive manufacturing because it is an additive process that reduces the amount of material wasted. Unlike the traditional method, 3D printing generates minimal waste.3D printing is ideal for producing small batches and meeting on-demand manufacturing needs. With 3D printing, it is possible to reproduce fine details and intricate features with high accuracy. 3D printing offers a variety of material options, such as plastics, metals, ceramics, and beyond. The use of 3D printing has brought about significant changes in various industries as it offers quicker and more versatile manufacturing processes. In the fashion industry, 3D printing has paved the way for exclusive and inventive designs, detailed accessories, and complete outfits, expanding the limits of what can be achieved in terms of shape, texture, and building (Spahiu, Canaj, Shehi 2020).

2.2.1 Attributes, methods and techniques of 3D printing

Creating a three-dimensional object layer by layer is the process of 3D printing, also known as additive manufacturing. The process of 3D printing starts with the designing of 3D digital

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model by using computer-aided design (CAD) software or by utilizing 3D scanning technology. To create a 3D model, slicing software is used to divide it into thin horizontal layers. These layers are then used as a guide for the 3D printer to build the model, with the software generating a set of instructions for each layer. These layers are printed by 3D printer can use different materials, including plastics, metals, ceramics, resins, and even food materials in some cases. The material is added or solidified in a precise manner, following the design. The printer creates the object by adding layers on top of each other, with each new layer sticking to the one below it. This method is called additive manufacturing, as opposed to subtractive manufacturing where material is removed from a larger piece to form the final shape (Gebler, Uiterkamp, Visser 2014). The printing process may differ depending on the type of 3D printing technology employed:

A. Fused Deposition Modelling (FDM) or Fused Filament Fabrication (FFF): The process of 3D printing involves heating thermoplastic filament until it melts, and then extruding the melted material onto a build platform in layers (Vanderploeg, Lee, and Mamp 2016).

B. Stereolithography (SLA) and Digital Light Processing (DLP): The process of solidifying liquid resin involves exposing it to UV light layer by layer. As each layer is completed, the build platform moves upward gradually (Vanderploeg, Lee, and Mamp 2016).

C. Selective Laser Sintering (SLS): Using a laser, powdered materials such as plastics or metals are fused layer by layer in a powder bed. The un-sintered powder provides support for the structure (Vanderploeg, Lee, and Mamp 2016).

D. Selective Laser Melting (SLM) and Electron Beam Melting (EBM): Metal powders can be melted selectively using a laser or electron beam to construct metal parts layer by layer (Vanderploeg, Lee, and Mamp 2016).

To ensure the object's structural integrity, cooling or curing processes may be necessary based on the material used for printing. This solidifies or hardens the layers. Once the printing process is finished, certain objects may need additional post-processing steps, like cleaning, smoothing, painting, or extra assembly. After printing, the object is carefully inspected for accuracy, structural integrity, and surface finish to ensure that it meets the intended specifications. This step is crucial in guaranteeing the final product's quality.

The duration of the entire process, from design to the completion of the object, can vary from minutes to hours or even days. This depends on factors such as the complexity of the design, the size of the object, the printing technology used, and the material selected.

3 Discussion

The influence of 3D printing on avant-garde fashion is significant. It has transformed the design process for creators, allowing for new possibilities in materials, aesthetics, and design boundaries. Material innovation, complex geometry, customization, reduced waste, innovative accessories, rapid prototyping, interdisciplinary collaboration, and futuristic aesthetics are some notable ways in which 3D printing has impacted avant-garde fashion.

The use of 3D printing technology enables designers to experiment with unusual and inventive materials that were once challenging to use in clothing design. The applications provide designers with the ability to create complex geometrics that would be difficult to achieve using traditional sewing methods. This technology allows for the realization of intricate designs that have interlocking parts and multi-dimensional forms. The avant-garde fashion movement values individuality and experimentation. With the help of 3D printing technology, garments can be customized to fit the unique body shape and measurements of the wearer. This emphasis on personal expression aligns perfectly with the avant-garde philosophy and challenges the limitations of conventional sizing. The conventional method of fashion production typically results in a large amount of waste due to fabric cutting and offcuts. On the other hand, 3D printing is a type of additive manufacturing process where the material is added layer by layer, thus reducing waste. This eco-friendly approach can be beneficial for avant-garde designers who prioritize sustainability. With this technology, designers can craft intricate and unique accessories, including shoes, headpieces, jewellery, and even wearable art, that challenge the boundaries of fashion and sculpture. 3D printing enables designers to create prototypes quickly, allowing them to experiment and refine their ideas without the limitations of traditional production timelines. As a result, avant-garde designers can iterate on their designs more efficiently, leading to faster development and innovation. The futuristic and unearthly aesthetics of 3D published designs align with the avant-garde's desire to challenge societal morals and comprehensions of fashion.

Conclusion

The relationship between 3D printing and avant-garde fashion is one of collective influence and invention. 3D printing technology has had a significant impact on the world of avant-garde

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fashion, and avant-garde fashion has been a driving force in pushing the boundaries of what is possible with 3D printing. This is how the two are nearly connected. Avant-garde fashion seeks to challenge conventions and explore new forms of cultural expression. 3D printing technology aligns well with this philosophy, offering designers a tool to create intricate, unconventional, and experimental designs that were previously impossible using traditional manufacturing methods. Avant-garde fashion often involves working with unconventional materials. 3D printing allows designers to experiment with a wide range of materials, from plastics to metals to flexible polymers, enabling them to create garments and accessories that embody their innovative vision. The intricate and complex shapes often found in avant-garde fashion are well-suited to 3D printing. This technology enables designers to bring their intricate geometrical concepts to life with precision, resulting in pieces that challenge traditional notions of garment construction. Both 3D printing and Avant-garde fashion embrace customization. Avant-garde designers can use 3D printing to create garments that are tailored to an individual's unique body shape and measurements, enhancing the personal connection between the wearer and the piece. Avant-garde fashion is characterized by experimentation and iteration. 3D printing allows designers to rapidly prototype and test their ideas, enabling them to explore different concepts, shapes, and forms in a shorter amount of time. Avant-garde fashion often blurs the line between fashion and art. 3D printing enables designers to create wearable art pieces that challenge traditional fashion norms and provoke thought, aligning with the avant-garde focus on innovation, creativity, and pushing boundaries. Both 3D printing and Avant-Garde fashion thrive on collaboration across different disciplines. Designers may collaborate with engineers, technologists, artists, and other experts to push the limits of design and technology. Avant-garde fashion can address cultural, social, and political issues through its designs. 3D printing technology can help amplify these messages by creating pieces that stand out and capture attention, effectively conveying the designers' intent.

In Summary, the relationship between 3D printing and avant-garde fashion is one of symbiosis, where avant-garde fashion leverages the capabilities of 3D printing to realise its innovative concepts, while 3D printing technology finds a canvas in avant-garde fashion to demonstrate its potential for pushing the boundaries of design, materials, and artistic expression.

Roles of author

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Virtual fashion: The new skin revolutionizing the fashion industry

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Abstract

The Fashion Industry recognized sustainability as an important issue for clothing retailers during the last decade, with increasing demand from consumers for products that are environmentally and socially sustainable as mentioned by Joergens. The fashion industry in its journey to adopt sustainability is facing various challenges in streamlining long supply chains and operations, redefining its business models. In the year 2020, the world witnessed humanitarian and economical losses in the fashion industry marked by declining sales, disrupted supply chains and even shift in customers buying behaviour. The Pandemic has reinforced the conscious choice of the customer by topic of sustainability in the spotlight by escalating and polarizing views around materialism, over-consumption and reckless business practices. Fast fashion popularised the idea of fashion and style with new and cheaper outfits while social media strengthened this by giving a platform to showcase one's identity through fashion choice. The hashtag #ootd reveals millions of posts and most of them will only be worn once and then discarded.

The virtual fashion or digital fashion brand that emerged in 2018 became a choice for fashionistas and fashion influencers to create their digital fame. Digital Clothing or virtual garments are created with pixels rather than textiles or fabrics. It is said that various events and economic fluctuations have influenced fashion in the past, similarly post COVID fashion industry is witnessing a digital revolution by engaging augmented reality and creating cyber fashion and accessories followed by retailing them. With the lack of physical contact and changes in consumption of fashion during this pandemic, it can be assumed that the next wave of the fashion cycle is going digital from avatars to magic mirrors the possibilities are endless. It has become the second skin or material for many influencers.

From pret to couture, fashion houses have started utilizing the services of the agencies to create 3-D models of their apparel and footwear to mitigate the carbon footprint by eliminating a typical production process. The paper aims to review the scope and limitations of integrating virtual simulation technology including virtual avatars in the real time fashion industry. In turn leveraging the efficacy of virtual fashion as a new skin or material that has possibility of mass production and can swung the fashion industry.

Keywords: Sustainability, Conscious consumption, Virtual fashion, Augmented reality, Virtual avatars, Contactless fashion.

1 Introduction

The Industrial Revolution 4.0 with its advent of rapid change in technology, Automation, the Internet of Things, Cloud Computing, Artificial Intelligence, Smart Factories, and Smart Manufacturing, to name a few has transformed and shaped our environment (IBM, 2022). Each industrial revolution and inventions of new technologies has resulted in enhancement of industries and human lives, through mechanization brought by the 1st Industrial Revolution followed by mass production and electricity in the 2nd revolution and IT systems and automation during the 3rd (Jin and Shin, 2021). The 4th Industrial Revolution capitalized on the previous digital revolution resulting in the synergistic effects of advancement in technologies (Philbeck and Davis 2019). The highlight of every industrial revolution in history was never just about the development of technologies itself. Rather, it was about enhanced productivity, with enhanced quality of human life which was made possible by innovative technologies and inventions (Jin and Shin 2021). Along with the other industries, the fashion industry has not been exempted from the influence of the digital transformation by bringing up revolutionary changes in operation and manufacturing process as well as in consumption practices by the customers.

The pandemic has expedited a decades-old trend that has seen growth in the fashion industry in terms of ethics, transparency, and sustainability as well as in terms of innovation and advancement towards digital. Unprecedented emergencies, disruptions, enormous order cancellations, and the swift closure of brick-and-mortar establishments were all brought on by the Covid-19 epidemic. Lockdowns everywhere brought to light the dangers of fast fashion, the complexity of the supply chain, and the difficulties of international sourcing.

A turning point in the fashion industry occurred in 2019, when the Dutch fashion start-up The Fabricant worked with block chain company Dapper Labs to auction their digital-only dress at Ethereal Summit (New York) for cryptocurrency valued at $9,500 (Roberts-Islam 2019). Followed by this, the unprecedented disruptions in supply chain connectivity, order cancellations of international sourcing, and the closure of brick-and-mortar establishments brought on by the Covid-19 epidemic (Alicke, Barriball, and Trautwein 2021). Fashion businesses were compelled to innovate by these significant value chain upheavals. Although video games have established the trend in digital fashion in recent years digital fashion has evolved beyond games and collided with culture and industry around fashion (Brachem and Stübbe 2021). This paper aims to analyse the scope and limitations of integrating virtual simulation technology including virtual avatars in the real-time fashion industry. In turn leveraging the efficacy of virtual fashion as a new skin or material that has possibility of mass production. Before proceeding further, it is important to understand the digital fashion and its evolution over past few years.

2 Digital Fashion

“Digital fashion refers to a practice that produces three-dimensional virtual clothing as prototypes or sample simulations for possible physical garments, and/or for datafied virtual, digital-only garment representations” (Särmäkari 2021). This intangible form of garment representation is considered as the next big thing or the new norm of the fashion or the future of the fashion industry. In media and professional discourse, the term "digital fashion" has two distinct connotations and is regarded as a process tool that aids in sales and design (McDowell 2019). Additionally, the phrase "digital fashion" can refer to a piece of clothing worn only in virtual settings where our identities and bodies are seamlessly integrated with those of our dressed-up avatars (Särmäkari 2022).

In 2018, the first apparel line to be sold exclusively online was unveiled by the Scandinavian store Carlings. They introduced a total of 19 items, each priced at £9. Customers gave Carlings a photo, and the store's 3D designers then altered the digital apparel to fit the customer. The first augmented reality graphic t-shirt, known as the "Last Statement T-Shirt," was released by the retailer later in 2019. With the help of a smartphone and Spark AR technology, the graphic design of this T-shirt may be altered. The design of the shirt can be altered with the Facebook and Instagram custom filters with it (Govisetech 2021). As mentioned previously/above, the sale of the Fabricant-created "Iridescence" outfit marks a turning point for digital fashion. This one-of-a-kind garment is a trackable, tradable, and collectible work of digital art that was auctioned via Portion as a pioneering block-chain transaction. Online apparel marketplace DRESSX, the first markets in the world to focus solely on digital fashion—clothes and accessories worn in virtual environments debuted in August 2020. London-based fashion label Auroboros became the first company to present a completely digital ready-to-wear line at the event. The Global Change Awards' signature event, the H&M foundation's Billion Dollar Collection, is a virtual line up of designs made by winners. The clothing was digitally produced by Mackevision, a unit of Accenture Interactive, who also used CGI character design technologies to create a digital model to "wear" the collection (Dey 2021).

2.1 Skins for virtual fashion

The origins of digital clothing can be found in "skins," which are garments and other embellishments for in-game characters. Skins, as they are commonly referred to in the video game industry, are virtual decorations used in many modern day, online, multiplayer video games to change the appearance of a video game avatar’s weapons or appearance in-game (Grove 2016 as cited in Haskell 2017).

Sonic Adventure 2 in the year 2001 established the concept of downloading skins which was free of cost. Further Elder Scroll 4 Oblivion game introduced horse armour which can be purchased using a small amount of money. It led to the creation of one of the most despised and successful business models in gaming, Microtransaction- the purchase of virtual items for a small amount of money in a game. Further another business model called battle pass in which the player was rewarded skins for completing challenges was incorporated by many games like Fortnite, Apex Legends and Warzone. The emergence of eSports caused a big shift in the way people purchased skins since they were motivated to do so after witnessing their favourite team using unique skins (Felix 2022). E-sports typically take place in Massive Multiplayer Online

Games (MMO), which are cooperative virtual reality environments that require an Internet connection to play. MMO paved way to online virtual community that allows players to create avatars to interact in the virtual world. This function enables online self-expression in addition to adding a social component (Jung and Pawlowski, 2014). Gamers frequently alter their look to "identify" with a video game character, either because they see similarities between themselves and the character or because they are attempting to build their ideal selves (Steinerte, 2021). Looy et al (2010) quotes that “players who customize their character and fantasize about it so that it more closely fits their ideal self-image should also identify more strongly”.

Players use an avatar to communicate with others and the surrounding virtual world in these computer-generated settings. A player's avatar, or virtual representation of themselves in the game, must first be created in order to access the game and be used to interact and explore the virtual world. The word “avatar” in this sense means “a graphical representation of a user within the environment which is under his or her direct control” (Allbeck and Badler 2002 as cited in Nadolny and Childs 2014). It is derived from the Sanskrit word avatârah which literally means descent. The words ava ("down") and tarati ("he crosses") combine to form the word avatârah. It therefore translates to "the crossing down" and usually alludes to a divinity taking bodily form (Isdale et al. 2002 as cited in Peachey and Childs 2011). Thus, adopting an avatar in a virtual world is a means of transitioning from the physical into the digital. Digital games have long featured fashion elements, often in very basic ways like the characters' outfits.

The announcement by Facebook CEO Mark Zuckerberg on rebranding and renaming his company as “Meta” in the year 2021 and the establishment of a so-called "Metaverse". The term "metaverse" refers to a shared 3D virtual environment where all activities can be carried out utilising augmented and virtual reality technology. According to Zuckerberg, it is a digital platform where you can perform all of your daily activities online while using a digital representation of yourself that resembles your real-life self. Shopping, watching films, putting on clothes and attending concerts are just a few of the potential activities. The fashion industry prepared for the metaverse actively by developing digital avatars in virtual worlds fashion brands by developing a market and business around them. Wearable NFT became a breakthrough for the fashion industry in convergence with technological advancement. NFT or the non-fungible tokens is a type of crypto-asset used to track the ownership status of digital things like photos, videos, and text (Wang, Ren, Li, Qi, and Zhou 2022). As stated by Williams

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in 2021, People are prepared to spend a lot of money on NFTs, digital collectibles, and the opportunity to live again in the metaverse (Joy et al. 2022).

3 Scope of Digital Fashion

Digital fashion offers untapped opportunities for the democratization of the fashion business, making it more accessible and inexpensive for people from all socioeconomic levels, generating new sources of income for fashion designers, and expanding avenues for creative self-expression (DRESSX, 2023). With the brands launching their fashion products on virtual platforms like metaverse, the demand of digital fashion is rising day by day. Virtual fashion has immense potential to transform the existing fashion industry.

3.1 Virtual avatars and digital identities

As McKenna et al (2001) quotes “the identity adopted in virtual worlds is actually a closer reflection of the self than many of identities we have within the physical world.” as cited in Childs (2011). A person's avatars may reflect them more accurately than their offline identities do (Taylor 2002 as cited in Childs 2011). Virtual clothing plays a key role in the creation of our identities when virtual—or partially virtual—bodies and are extensions of ourselves rather than purely virtual objects (Liao 2011). Wearing a virtual garment may be considered as a vestmental embodiment. Since we are accustomed to experiencing the actual garments, we wear while being watched by others, wearing virtual clothing transforms us into our own perceivers.

MMORPGs, or massively multiplayer online role-playing games, like Second Life launched in 2003. It comprises of a parallel universe made up of real-time interactions taking place in a 3D online persistent space totally created and evolved by its users. An avatar is used by MMORPG players, to navigate through Second life's and it constitute a sizable niche market for virtual clothing. Additionally, the elimination of mobility restrictions based on gender that were mediated by garment constructions is made possible by the physical intangibility of clothes in virtual space (Etengoff 2012).

The expanded versions of our bodies gain importance as we immerse ourselves more in the virtual world. Distinctions between the physical and virtual worlds become less significant, and dressing for the virtual world becomes a habit. The fundamental benefit of digital fashion is that it gives customers more control than ever before over their online image (Brachem and Stübbe 2023).

3.2 Sustainability

A significant problem for the global fashion business is the unsustainable environmental pressures that its product's manufacturing and eventual disposal creates on the environment. As quoted by Kenneth P. Pucker "The sad truth however is that all this experimentation and supposed "innovation" in the fashion industry over the past 25 years have failed to lessen its planetary impact". According to current estimates, the fashion industry is to blame for 20% of global wastewater and nearly 2.1 billion tonnes of annual carbon emissions. 73% of recycled textile waste is dumped in landfills; only 1% of it is used to create new clothing. In order to put the industry on a more sustainable foundation, the technological breakthrough of digital fashion may provide a potential solution (Planet Tracker 2022).

The introduction of 3DVD technology causes a structural change in the conventional supply-chain paradigm utilized by the fashion industry. The use of 3D modelling enables the integration, optimization, and augmentation of the design and development workflow. This digital technique fosters design innovation, speeds up manufacturing, makes the most use of materials for physical samples, and lowers costs. Digital clothing facilitated the process flow and designing and prototyping are transformed into a singular digital process that unifies pattern-making, fitting, and testing in a single virtual environment for accelerated iteration cycles. Virtual samples can be completed in a few hours as opposed to taking days or weeks. This technique also reduces or completely does away with the requirement for physical sampling, manual labour, and fabric use by prototyping a single altered physical sample at the end of several virtual encounters (Casciani, Chkanikova, and Pal 2022). The necessity for physical production is diminished by virtual fashion, reducing the environmental impact of conventional manufacturing methods. It lessens waste, stops the usage of raw materials, and prevents emissions linked to logistics and transportation.

3.3 Influencer marketing

Influencers on Instagram often introduce their tested products to provide comments or promote them to other users online. In actuality, influencers get money off of their images, therefore they place a high value on image quality (Katsha 2021). Influencers on Instagram through the tag # OOTD (Outfit Of The Day) to display, resulting in a large number of advertising content (Abidin 2016). #OOTD was founded a decade ago by the hashtag's originator Karla Reed (2020) and was coined a national holiday by reality television star Stassi Schroeder in 2018 (Huang and Copel 2020 as in Inniss 2018). It became an activity where a person taking some straightforward photos to display what they wore that day became a quick and simple method to show off one's sense of style through social media. OOTD posts have evolved into a popular way for influencers to showcase the goods they are supporting, serving as a marketing tool for companies. The trend of OOTD increased the number of images. Alice Gividen, editor of WGSN's global trend edit The Feed, echoes this. "Once an outfit has been 'gridded', there's a real reluctance for shoppers to share the look again," she says. "The gratification that comes with a new outfit is gone, as the compliments stop coming." (Gividen Alice, as cited in Benson 2019).

According to research by Nutmeg (2019), the average price of a #OOTD on Instagram was £731.90 in the year 2019. There are more than 426 million posts with the popular hashtag #ootd on Instagram, according to a simple search. Get Ready With Me (GRWM) is the most recent iteration of OOTD on TikTok. Although the concept is the same, the video style focuses on putting together an outfit and frequently explains the logic behind it (Benson 2019). Given the extensive number of resources required for the manufacturing, ordering and delivery of physical garments, this trend has become a hindrance to fashion's suitability ambition (McKinsey 2021).

With the emergence of platforms like DressX, consumers may now buy a digital garment in the form of an image that they can 'wear' on social media using photorealism technology. When compared to their physical counterparts, such digital clothing consumes a fraction of the resources. According to DressX research, a digital fashion item has a 97% lower carbon footprint than its physical counterpart (Ellen MacArthur Foundation 2021). For brands and influencers to work together, virtual fashion creates new possibilities. Influencers can show off digital attire and accessories while promoting companies and interacting with their followers in captivating and eye-catching ways.

3.4 NFTs and digital ownership

The concept of Non-Fungible Token (NFT) was introduced into the market through the foundation and development of Cryptocurrencies Ethereum and blockchain technology. An NFT (non-fungible-token) to put it simply, is a certificate that one owns something digital, with the owner being the sole possessor of said medium (Breiter and Siegfried 2022).

Luxury apparel manufacturers gain from NFT ownership, stability, and royalty acquisition. Many fashion brands use the internet to reach a wider audience, but their expensive prices make replicas and knockoffs popular. Businesses lose a lot of money when counterfeit goods are sold, but NFTs can minimize or even eliminate these losses. By utilising block chain technology, NFT secure authenticity of cryptographic assets which makes it nearly difficult to change or falsify the data (Kirjavainen 2022). Following over a year of store closings, the fashion sector is now looking into fashion technology, particularly NFTs (Dhama and Arora 2023). NFTs have several applications in the fashion industry, but the three most important ones are (1) authentication and traceability, (2) marketing, and (3) virtual fashion (Guinebault 2022). NFT shaped the monetization strategy of gaming companies with purchase of skins and other accessories for virtual avatars.

The Fabricant, DressX, and RTFKT, among other digital fashion designers, are finding markets for digital apparel that has been NFT-authenticated as buyers look to collect and invest (Mckinsey 2022). One such example is RenaiXance a limited edition, digital garment collection co designed by RTFKT x The Fabricant. As cited by Debayan Samanta, a digital artist Beeple is entitled to 10% of the sale price in the event that any of his NFTs are sold on a secondary market, for instance. NFT authors may be paid royalties on each sale or transfer of their works. Due to the adoption of NFTs by the fashion sector, tokens may be used to offer customers a range of incentives, including early access to the newest items, discounts, membership in exclusive clubs, and more (Samanta 2022).

3.5 Integration of AR VR

Olsson et al (2013) define Augmented Reality as a technique ‘to integrate both actual and digitally produced by computers information into the user's perception of the physical world so that they seem as one environment. Through a virtual overlay that may add pictures, text, movies, or other virtual items to the user's perspective of the actual environment in real time, augmented reality merges the virtual and real worlds. By immersing consumers in virtual, fascinating 3-D environments, VR uses a wearable device (usually a headset) to filter out sensory stimuli from the "real world" and offer a potentially more inventive and engaging purchasing environment (Bonetti, Warnaby, and Quinn 2017).

Jayamini et al (2021) suggests that the AR applications for fashion designing section consists of that would enhance designers’ skills and knowledge, self-customization section and enhancing customer experience enhance designers’ skills and knowledge. "Digital fashion" only expands the jurisdiction to include a wider range of technical digital skills that overlap with other occupations because it still relies on the tacit knowledge and artistic vision of the designer as a tool for optimizing, virtualizing, and digitalizing the design process and production. The designer becomes into a digital craftsperson employing the embodied technical fashion expertise. The term "digital fashion" recasts the position of a fashion designer as a digital artisan, an independent designer-maker. But because co-creation, collaboration, and personalization have become the norm, professionalization is pursued with a focus on ethical and intelligent procedures rather than the authority of the designer (Särmäkari 2020).

3.6 Customization

The main advantage of digital fashion is that it provides consumers greater control over their online persona than ever before. This is because platforms for digital fashion provide consumers with more options for self-expression than the real world does (Rijmenam 2022).

Consumers may customize their garments using digital technology to suit their own preferences, increasing the likelihood that they will be happy with their purchase. This might range from choosing an unusual colour or pattern to embellishing a garment with writing or bespoke embroidery. Even 3D design tools are available from certain online clothing retailers, enabling customers to design their own unique clothes from scratch (Digital Model Agency 2023).

3.7 Virtual fitting room

With advances in virtual reality that allow customers to sample things before they buy them, the retail sector has made significant progress toward innovation. Customers may shop from the comfort of their homes and skip the mall line ups and enables customers to snap pictures of themselves wearing various ensembles before making an online purchase. According to Zakeke (2022), it is an excellent strategy for fashion retail establishments to enhance customer satisfaction, boost traffic and sales. Virtual try-on has become an integral component of the client experience as the fashion industry undergoes fast transformation and the need for customisation rises. 'Magic mirrors,' often referred to as 'virtual mirrors' or 'smart mirrors,' are prominent instances of AR applications (Javornik 2016c). Since 2010, so-called "Magic Mirrors," notably in retail settings, have grown in popularity as a way for customers to virtually "superimpose" clothing on themselves (Boardman, Henninger, and Zhu 2019). The system makes use of a somatosensory virtual changing room, OpenGL 3D graphics, and Azure Kinect somatosensory technology. The user may add several designs to the fabric and can attempt virtual fitting.

4. Limitation

According to the research conducted by Evridiki and Bilalis (2017) vendors, accept the technological advancement credit the necessary transformation. However, they identify the issues as investing time and energy in implementing the new technology. Another drawback observed from the academicians point of view was the amount of time required to understand this new technology and how inadequate the tool might become when compared to an inexperienced 3D user and a skilled basic technician. The unemployment will be inevitable once the technology is fully integrated. Though the fashion industry has started integrating the virtual simulation technology, but at present, lot of work has to be done in the areas related to Fit, Impact of NFT's on environment, Integration of AR and VR, 3D modelling etc, which are discussed below.

4.1 Fit

Attaining virtual is difficult task. Evridiki and Bilalis (2017) argues that a physical sample is needed; to check the feel of garment, how the avatar reacts and moves with the virtual garment on. The fit can be defined as shape and size of the garment relative to the shape of the body, it can be influenced by the fabric's physical and mechanical properties including tendency to drape, distort, stretch, shrink due to the stress induced while wearing.

4.2 Environmental impact of NFT

The majority of NFTs are acquired in ways that are far from sustainable, despite the fact that by their very nature, they don't produce any physical trash. On the surface, these NFT collections may appear to have no bearing on fashion's real-world challenges, such as sustainability (McClelland 2023). NFTs essentially do not have any negative environmental effects, but their production has a negative impact on the environment. An NFT's information is tokenized and saved on the block-chain during the "minting" process, which creates it (Garnett 2022). NFTs make use of block-chain technology, primarily operating on the Ethereum block-chain, to verify ownership, provenance, and scarcity of the digital assets they represent. This technology guarantees immutability and transparency, fostering confidence and authenticity in the digital sphere. Minting an NFT involves intricate calculations and demands a lot of processing power. This power use is a result of the Proof of Work (PoW) consensus method used by the underlying block-chain technology (Akash 2023). In order to confirm and transmit transactions, Ethereum employs the Proof of Work (PoW) consensus process, which verifies NFTs by utilizing computational puzzles that computers compete to solve (NFT Explained Info 2023).

NFT transactions continue to increase the carbon footprint of the fashion sector, even as they reduce water use and dependency on supply networks. However, not all NFTs are sold on block-chains with high environmental impact, and some fashion businesses have designed NFTs with far lower environmental impact than others. This information is crucial for customers to have so that the consumers may make wise choices while making online purchases (McClelland 2023).

4.3 Implementation of AR/VR

Boardman, Henninger, and Zhu (2019) there is currently relatively little research particularly examining AR/VR in the context of fashion retail and its effects on the sector as a whole, there is plenty of room for possible usage of them there. Boardman, Henninger, and Zhu (2019) also suggests the scope of future studies in looking at the advantages and disadvantages of deploying AR and VR technologies from the viewpoints of retailers and customers, as well as quantify the direct advantages that either technology could provide to a business. VR and AR also confront difficulties with internet security and data breaches, just like any other sort of technology. Authors such as Hwang et al (2012), Bastug et al (2017), and Bonnetti et al (2018) insist that personal data storage is currently not fully secured and thus, can be accessed relatively easily as cited in Boardman, Henninger, and Zhu (2019). The implementation issues resulting from AR and VR include the necessity for hardware, a specialized cabin, surroundings, cheaper and more effective hardware and technology hiring, and a lack of original and distinctive content (Kumari, and Polke 2019).

4.4. Challenges faced by three-dimensional virtual simulation technology

Zhang (2022) argues that there are still flaws in the accuracy of 3D measurement data inconsistency between fashion design and human model. Although 3D virtual simulation technology is able to design clothes that meet the needs and aesthetics of the public, the problem of repeated clothing patterns persists due to the limitations of technical means. For example, in CLO3D software, when clothing patterns are added to clothing pieces, duplication occurs (Li 2019).

5. Conclusion

The paper highlights the influence of Virtual Simulation technology in the field of fashion which ranges from virtual avatars, NFT's, digital fashion, virtual mirrors etc. The digital fashion has given new direction to fashion industry where products could be visualized on the photograph in the form of digitally rendered garment or accessory, hence paving way for sustainability through virtual customization. The recent development in AR and VR technologies and with advent of Metaverse, the Luxury brands and designers have started exploring the potential of the digital technology by working in tandem with gaming industry and creating new skin for avatars, launching their Virtual Merch stores and booths for enhancing the immersive experience for the users. This technology is not limited to the virtual platform but has been integrated for real time production process as well. Where product lifecycle has been substantially reduced and products now no longer go through the cycle of sampling and amendments, but instead once virtual samples are approved by the buyers it directly goes to the production. Hence reducing the time, energy, labour and fabric consumption and eliminating the dead stock created before launch of every collection. The technology has the potential to replace the fast fashion in the coming years but at presented it is at the nascent stage and poses limitations related to Fit, environmental impact of NFT's, threats of data breeching while implementing the technology. Future research in this direction will help in seamless integration of the technology for better immersive experience and will reduce the sustainability concerns posed by fashion industry.

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Unravelling the thickness dependence: Achieving exceptional nitric oxide gas detection using electrospun zinc oxide nanofibers

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Abstract

Gas sensing technologies play a pivotal role in healthcare applications, particularly in the early detection of respiratory diseases. Nitric oxide (NO) stands as a crucial biomarker for diagnosing conditions like asthma. Nanostructured semiconducting metal oxides, exemplified by zinc oxide (ZnO), have emerged as highly promising sensing materials due to their exceptional properties. This study is dedicated to the investigation of sensing layer thickness employing electrospun ZnO nanofibers for the detection of NO gas. By manipulating the thickness of the electrospun ZnO membrane, its impact on sensing performance at 200°C was systematically explored. The outcomes unveiled that thicker electrospun ZnO membranes exhibit heightened sensitivity, likely stemming from augmented charge mobility and an increased exchange of charge carriers during the oxidation/reduction mechanism. This research significantly contributes to the comprehension of how the structural attributes of the sensing layer influence the performance of metal oxide-based gas sensors. Furthermore, it underscores the potential of structural control to achieve enhanced sensitivity towards NO gas.

Keywords: Nitric oxide, Electrospun nanofibers, Zinc oxide, healthcare Sensor application

1 Introduction

Gas sensing technologies play a critical role in various applications, particularly in the field of healthcare, where the early detection of respiratory diseases is of paramount importance. One specific target gas of great significance in healthcare is nitric oxide (NO), which serves as a crucial biomarker for diagnosing respiratory conditions, such as asthma. Accurate real-time monitoring of NO within the low-concentration range of parts per billion (ppb) to parts per million (ppm) holds significant value. Breath sensors based on nanomaterials (NMs) show potential as clinical diagnostic tools because such sensors are small and easy to use (Wang et al. 2008). Nanostructured semiconducting metal oxides have garnered significant attention as promising sensing materials due to their remarkable properties (Mercante et al. 2019), including high sensitivity, stability, affordability, rapid response, simplicity, portability, and ease of manipulation. ZnO is a well-known n-type semiconductor with wide band gap (3.37eV) and large excitation binding energy (60eV) material, that has been extensively used in gas sensing devices due to the low production cost and the non-toxic property. ZnO with nanostructure is particularly promising because the large surface-to-volume ratio enhances the sensitivity (Singh et al. 2019).

There are several materials synthetic methods to produce a broad variety of nanofibers sensing materials based on SMOs, such as melt-blown (Han, Bhat, and Wang 2016; Medeiros et al. 2009) self-assembly (Yu et al. 2003), solution blow spinning (Medeiros et al. 2009) force spinning (Agubra et al. 2017), and electrospinning (Dai et al. 2011). Electrospinning is a straightforward (Abideen et al. 2017), versatile, and low-cost route to produce different kinds of nanocrystalline metal oxides with a highly porous fibrous morphology (Zhang et al. 2010; Xue et al. 2019; Lu, Wang, and Wei 2009). By employing the electrospinning technique followed by calcination, ZnO can be transformed into nanofibers, leading to enhanced gas sensor performance. The high aspect ratio, surface-area-to-volume ratio, and the ability to create diverse nanostructures and controlled shapes contribute significantly to improved sensing capabilities (Xuan et al. 2020). Electrospinning is a manufacturing technique that uses an electric field to create ultrafine fibres or nanofibers from a polymer solution or melt. During the process, a charged polymer solution is extruded through a fine nozzle, and the electric field forces the polymer to stretch and form thin fibres as it travels to a collector. These nanofibers have a wide range of applications in fields such as materials science, nanotechnology, and biomedical engineering due to their high surface area and unique properties.

There have been relatively few studies investigating the influence of the electrospun nanofiber structure in the sensing membrane of sensors designed for NO gas detection. Therefore, we tried to fill this research gap. The influence of electrospun ZnO membrane thickness for NO detection at 200°C regarding to sensing mechanism of NO gas was carefully studied in this work. The studies shows that thicker electrospun ZnO membrane shows higher sensitivity. This can be due to better charges mobility and more exchange of charge carriers during oxidation/ reduction mechanism hence enhance the gas sensing response.

2 Materials and methods

2.1 Synthesizing ZnO nanofibers

Poly (vinyl alcohol) (MW = 89,000 – 98,000 and 99+% hydrolysed) and zinc acetate dihydrate ((CH3CO2)2Zn) obtained from Sigma Aldrich Corp (France) were utilized without any further processing or refining. Porous ZnO nanofibers were synthesized by electrospinning technique using electrospinning cabin (Fluidnatek/LE 50, Bioinicia, Spain). Zinc acetate (ZnAc) with the ratio of ZnAc:PVA=2 was prepared in distilled water followed by ultrasonic; then 15wt% polyvinyl alcohol (PVA) polymer was added to the solution. 1wt% Triton -X was added to ease the process of electrospinning. The solution parameters such as viscosity, conductivity, and surface tension were carefully studied. Electrospinning parameters such as voltage, distance and feedrate were optimized using design of experiments (DOE) software. Electro spun membrane were calcinated at 600° C for 2 hours and heating rate of 0.5° C/min using a calcination system (Nabertherm Co, 30-3000 °C, Germany) to remove the PVA and obtained ZnO nanofibers.

2.2 Characterization

The structural qualities of ZnO nanofibers were examined using a Scanning Electron Microscope (SEM) (Phenom ProX, ThermoFischer Scientific, US). The diameter and surface porosity of membrane before and after annealing were studied by MATLAB software. The viscosity, conductivity and surface tension of solutions were characterized using Lamy Rheology Viscometer RM100 Plus, Mettler Toledo Seven Direct SD23, GBX Instrumentation Scientific 3S, respectively. Interdigitated electrodes were fabricated by as-spun ZnO nanofibers and tested by home-made sensitivity device.

2.3 Sensing measurement

For the sensing measurements, one layer and three layers of as-spun ZnO nanofibers was put on the interdigitated electrodes (Figure 1). Ethanol droplet followed by heating at 300 $^{\circ}$C caused increasing the adhesion of layers to the Interdigited electrodes. To create a three-layer sensor, three separate layers of calcinated ZnO membrane are deposited on top of each other, with all of them positioned on the electrode. Thereafter, two prepared sensors were tested in 5 ppm and 500 ppb of NO gas at 200 $^{\circ}$C.

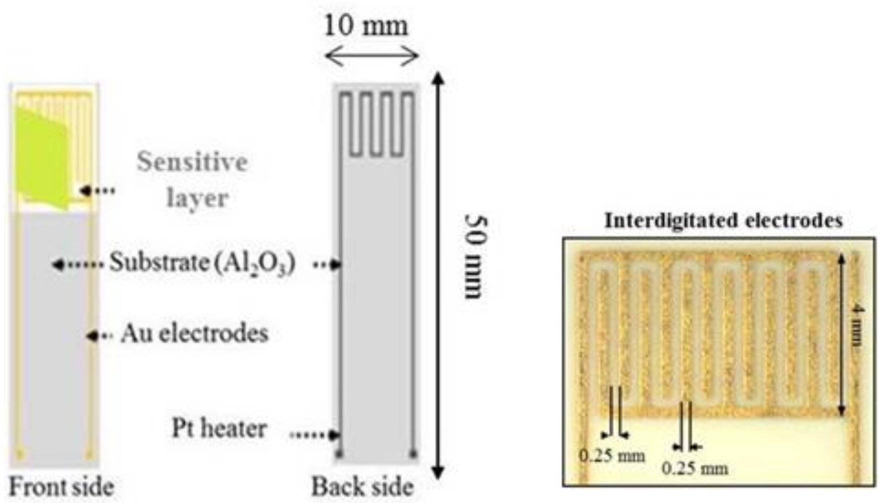

Figure 1 Image of electrode used for producing the sensors

Figure 2 demonstrated the whole process of designing the sensors.

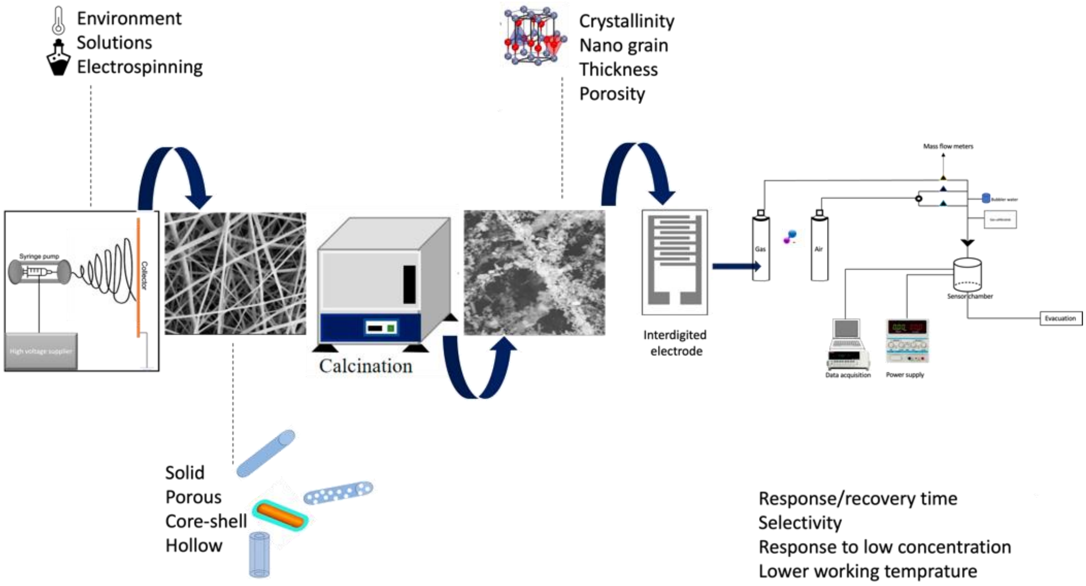

Figure 2 The process of producing the sensors

3 Results and discussions

To elaborate the influence of thickness on sensitivity and response of sensors towards NO gas, one layer and three layers of as-spun ZnO nanofibers were analysed. To understand the structural effectiveness, electrospinning parameters related to the solution and situation were measured.

3.1 Solution properties

As the properties of the solution plays crucial rule in the final structure of electrospun nanofibers, Table 1 represent these parameters (Supaphol and Chuangchote 2008). These measurements were done by the related instrument is mentioned in characterisation part.

Table 1 – Solution properties for electrospinning

Solution parameters	Viscosity (Pa.s)	Conductivity (µS/cm)	Surface tension (mN/m)
ZnAc:PVA	24.94 ± 0.13	9407.5 ± 48.33	51,42 ± 1,562

3.2 Electrospinning parameters

To obtain uniform nanofibers, DOE was applied. The range of voltage, feedrate and distance imported to DOE software was 10 – 22 kV, 10 - 22 cm and 60 - 400 ul/h, respectively and the optimized parameters are 16cm, 300 ul/h and 20kV.

3.3 Surface morphology

The nanofibers diameter and as-spun membrane weight are presented in table 2. According to Wang et al. (2008) study, ZnO nanofibers have the potential in excellent sensitivity and fast response and recovery. However, the gas-sensing properties based on pure electrospun ZnO nanofibers have not been reported to detect NO gas.

Table 2 – ZNO nanofibers diameters and weight

Before calcination		After calcination	
Diameter (um)	**Wight of 3cm*3cm(mg)**	**Diameter (um)**	**Wight of 3cm*3cm(mg)**
1.19±0.2817	24.94 ± 0.13	0.66±0.16	39.32

Figure 3 shows the SEM image of the ZnO nanofibers, indicating that the fibres had a rough surface, and were formed through the agglomeration of ZnO nanoparticles. As it can be seen, by removing PVA after calcination, the form of fibres is remained. Also, the diameter and weight decrease.

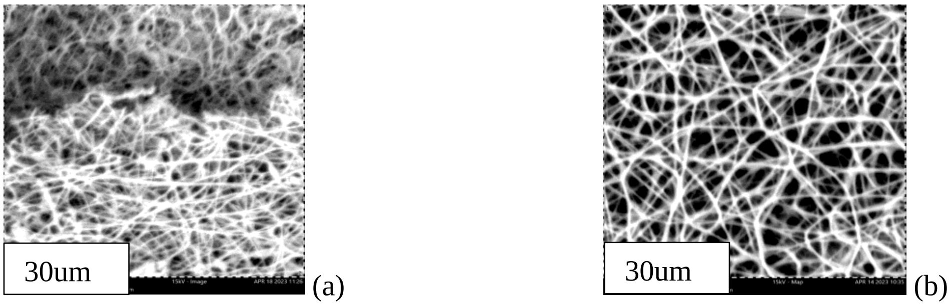

Figure 3 SEM images of Nanofibers (a) before and (b) after calcination

3.4 Sensor performance and sensing mechanism

As it is demonstrated in Figure 4, the response of three-layer sensor is almost 6 times better than one layer sensor. Three-layer electrospun ZnO showed an excellent response of 30 towards NO gas.

In ZnO nano-crystalline structure, the electron trapping sites at grain boundaries control electron conduction. Increasing thickness indicates an improvement of compactness of the ZnO layers as Yergaliuly et al. (2022) showed in their studies.

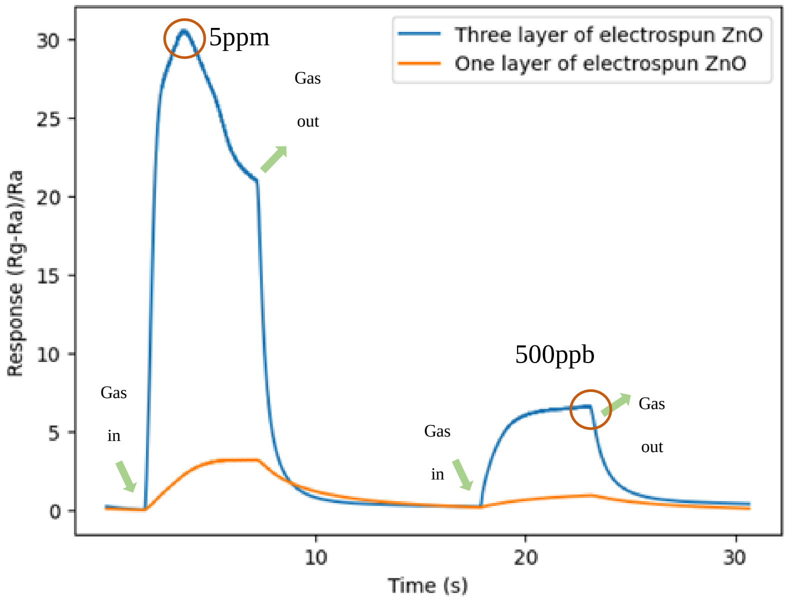

Figure 4 Dynamic diagram of sensor response at 200°C towards NO gas

The bandgap energy values slightly increase with the ZnO film thickness. Electrons in the metal oxide semiconductor experience the periodic potential of the ZnO crystal lattice. This potential leads to the increasing of the bandgap energy. Additionally, a change in the bandgap is associated with a change in the dislocation density, lattice strain, and the formation of defects in the ZnO (Soltabayev et al. 2021). Electron mobility refers to the ability of electrons to move through a material. In the context of gas sensors, it has been observed that thicker sensor layers tend to exhibit higher electron mobility. This characteristic becomes significant when the sensor is exposed to gas molecules. When a gas interacts with the surface of a sensor, it can induce changes in the electronic properties of the material, including its resistance. In thicker sensor layers, the increased electron mobility allows for a more pronounced effect on the resistance when gas molecules come into contact with the surface. The interaction between the gas and the sensor surface can lead to various phenomena, such as adsorption or chemical reactions. These processes can modify the charge carrier concentration or alter the conductive pathways within the material, ultimately resulting in changes in resistance.

By utilizing thicker sensor layers, the sensitivity of the gas sensor can be enhanced. This means that even small concentrations of gas molecules can induce significant changes in resistance, making it easier to detect and measure the presence of specific gases or analyse their composition.

It's important to note that the design and optimization of gas sensors involve a balance between various factors, including sensor thickness, material properties, and specific target gases. Researchers continue to explore and refine sensor technologies to improve their sensitivity, selectivity, and overall performance.

Conclusions and recommendations

In conclusion, the application of nanostructured semiconducting metal oxide materials, such as zinc oxide (ZnO), in gas sensing applications demonstrates significant potential for the precise detection of nitric oxide (NO) in healthcare environments. This study primarily delved into the influence of the electrospun layer thickness of ZnO nanofibers, which exhibited enhanced gas sensor performance owing to their remarkable attributes, including a high aspect ratio, surface-area-to-volume ratio, and controlled nanostructure. Through a comprehensive exploration of the impact of electrospun ZnO membrane thickness on NO detection, we have established that thicker membranes exhibit heightened sensitivity. This phenomenon can be ascribed to the enhanced charge mobility and increased exchange of charge carriers during the oxidation/reduction mechanism. These findings underscore the pivotal role of the sensing layer's structure in gas sensing performance and underscore the substantial potential of ZnO nanofibers in advancing NO detection capabilities.

Further research in this domain, with a specific focus on reducing the working temperature and investigating the influence of nanofiber structure on sensing performance, is highly recommended. Such endeavours will facilitate the comprehensive exploration of the extensive capabilities offered by nanostructured semiconducting metal oxide materials. This, in turn, will propel the development of gas sensors that are not only highly sensitive but also exceptionally selective, thereby significantly contributing to the diagnosis and monitoring of respiratory diseases in healthcare settings.

Roles of author

Writing the Original Draft (N.K.); Writing-review and Editing (E.M., H.G., R.B., D.L.); Software (L.A.); Over all supervision (M.L.).

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Conflict of interest

The author declares that there is/are no conflicts of interest.

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Optimising stitching parameters for compound fabric structure of knitted and woven fabrics

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Abstract

This study aimed to investigate the compound fabric structure by combining knitted and woven fabrics. This investigation aimed to establish the optimal direction for fabric join in order to achieve superior seam strength. The stitching parameters were optimized to achieve maximum performance in terms of sewability, durability, and strength of the compound fabrics. The optimized parameters were determined using various tests, including seam strength, seam slippage, and stitch density. Furthermore, the sewability of the compound fabrics was evaluated using a sewing machine and the stitch quality was analysed. The results of the study demonstrated that the compound fabric structure can be used to produce high-quality fabrics with improved properties compared to conventional fabrics. The compound fabric structure can be tailored to meet the specific requirements of these applications, providing better performance and enhanced comfort. Overall, the results of this study highlight the potential of the compound fabric structure as a new approach for producing high-quality fabrics with improved properties and various applications.

Keywords: Compound Fabric Structure, Knitted, Woven, Stitching, Sewability

1 Introduction

In the dynamic apparel industry, meeting the high demand for diverse fashion products is crucial. Achieving and maintaining top-notch quality is essential, influenced by factors such as raw materials, seam quality, and sewing performance. This directly impacts the sewability of the product, referring to its stitching ability. An emerging trend involves combining woven and knitted fabrics, with a focus on durability and functional requirements. Seam failure can occur due to fabric or thread breakage, compromising garment quality and demand (Kaniz et al 2015a, b, Kayalvizhi and Gokarneshan 2021, Rajput et al 2018, Abdel 2016, Golomeova 2017, Islam 2018). To address these challenges, comprehensive tests were carried out on seam strength, seam efficiency, seam puckering, and seam slippage of compound fabric. By optimizing sewability and ensuring superior seam quality, one can able to enhance the overall appeal and performance of garments.

The objectives of this study were to study and optimise the sew ability of compound fabric, and to improve seam quality of woven and knitted fabric.

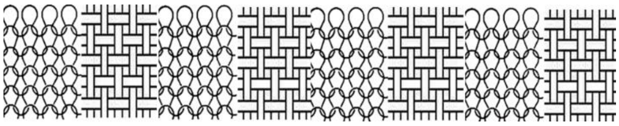


Figure 1 Compound fabric of woven and knitted structure

2 Materials and methods

Cotton woven and knitted fabrics were sourced from Shri Renukamata Textiles, Laxmi Industrial Estate, Hatkanangale. Properties of the fabrics are given in Table 1. The quality of a seam can be significantly influenced by the choice of sewing thread, including factors such as the type, size, and construction of the thread. Three spun polyester sewing threads, each with a distinct ticket number (50, 80, and 120) were selected and procured from Ken Enterprises Ichalkaranji.

Table 1 Fabric properties

Sr no.	Properties	Woven Fabric	Knitted Fabric
1	EPI/WPI	58	30
2	PPI/CPI	45	53
3	Thickness (mm)	53	43
4	GSM (g/m^2)	165.00	162.67
5	Cover factor of woven fabric	23.90	-
6	Tightness factor of knitted fabric	-	15
7	Warp way tensile strength (kgf)	39.20	-
8	Weft way tensile strength (kgf)	19.60	
9	Bursting strength	-	5.886 (bar)

In this investigation, four fabric samples were created by combining various directions, including warp-wales, warp-course, weft-wales, and weft-course. The seam strength and variations thereof were carefully measured and reported. A subsequent investigation was conducted to explore the impact of various factors i.e., seam type, ticket number, and stitch per inch on sewability.

Based on the information presented in the Table 2, a compound fabric was created to assess its sewability using different process parameters. Three factors were identified, each with three distinct levels. Firstly, three types of seams were selected: superimposed seam, lapped seam, and flat seam. Additionally, spun polyester sewing threads were utilized, varying in ticket numbers (50, 80, and 120), while Stitches per Inch (SPI) remained consistent at 10, 12, and 14. Since each factor had three levels, this constituted a 3^3 factorial experiment, requiring a total of 27 samples. However, to streamline the experimental process, Taguchi's L9 orthogonal array was employed, resulting in the reduction of samples to 9. Table 3 illustrates the implementation of Taguchi's L9 orthogonal array for this experiment.

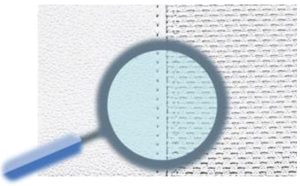
Table 2 Experimental design

Sr. No	Factors	1	2	3
1	Seam	Superimposed seam	Lapped Seam	Flat Seam
2	Ticket Number	50	80	120
3	Stitches per inches	10	12	14

Table 3 Specimens design

Specimen No.	Seams	Ticket number	Stitches/inch
S1	Superimposed seam	50	10
S2	Superimposed seam	80	12
S3	Superimposed seam	120	14
S4	Lapped Seam	50	12
S5	Lapped Seam	80	14
S6	Lapped Seam	120	10
S7	Flat Seam	50	14
S8	Flat Seam	80	10
S9	Flat Seam	120	12

The sewability performance of union fabrics can be influenced by various properties of both seamed and unseamed fabric. Various characteristics of woven, knitted as well as compound fabric samples were measured using standard methods and shown in Table 4.



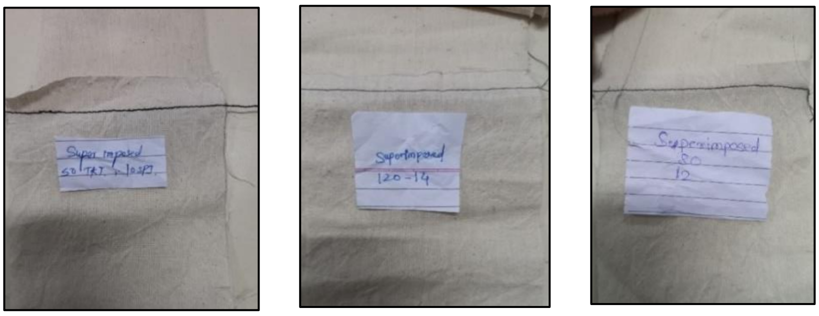


Figure 2 **Figure 3**

Figure 2 Illustration of the specimen; Figure 3 Fabric samples

Table 4 Testing methods

Sr No.	Tests	ASTM	Machine
1	Tensile strength of the fabric	ASTM D5034	Instron/ Fabric strength tester
2	Seam strength	ASTM D1683	Instron/ Fabric strength tester
3	Seam efficiency	-	Formula
4	Seam Puckering	-	Formula
5	Seam slippage/opening	ASTM D4034	Fabric strength tester
6	Bursting strength	D3786 / D3786M – 18	Bursting Strength Tester
7	Thickness	D1777 - 96(2019)	thickness gauge
8	GSM	D3776 / D3776M – 20	
9	EPI, PPI for woven fabric	D3775 - 17e1	Pick glass
10	Cover factor for woven fabric	-	Formula
11	WPI, CPI For knitted fabric	D8007 - 15(2019)	Pick glass
12	Tightness for knitted fabric	-	Formula

Seam efficiency, seam puckering can be measured using following equations.

1) Seam Efficiency = Fabric Strength with Seam / Fabric Strength without Seam
2) Seam Efficiency % = (Seam Strength / Fabric Strength) x100.
3) Seam puckering (%) = (ts - 2t) / (2t) × 100.

ts= seam thickness, t= fabric thickness

3 Results and discussion

Seam strength, seam efficiency, seam slippage/opening of specimens are presented in Table 5. Different factor's significance on the different properties of compound fabric is reported in Table 6. No statistical significance was found among different properties of the fabrics.

3.1 Preliminary study

The direction or grain line of the fabric during the garment stitching process plays a significant role in determining the properties of the final garment. Different directions can impart distinct characteristics, such as warp-wise grainline providing stability and weft-wise grainline offering stretchability. To investigate this phenomenon, a preliminary study was conducted involving the selection of four fabric samples that combined different directions of woven and knitted fabrics, including warp-wales, warp-course, weft-wales, and weft-course. Seam strength was measured using these four samples. Based on the findings of this preliminary study, final tests were conducted using samples exhibiting satisfactory tensile strength. The results of the preliminary study are presented in Table 7 and Figure 4.

Table 5 Specimen properties

Specimen no.	Seam	Ticket Number	Stitches /Inch	Seam Strength (kgf)	Seam Efficiency (%)	Seam Slippage /opening (mm)
S1	Superimposed seam	50	10	12.2	31%	25
S2	Superimposed seam	80	12	13.6	35%	15
S3	Superimposed seam	120	14	14	36%	5
S4	Lapped Seam	50	12	15.6	40%	3
S5	Lapped Seam	80	14	11	28%	1
S6	Lapped Seam	120	10	14	36%	5
S7	Flat Seam	50	14	15.8	40%	3
S8	Flat Seam	80	10	12.4	32%	4
S9	Flat Seam	120	12	14.2	36%	2

Table 6 Significance

Properties	Seam	Ticket number	Stitches /inch
Seam strength (kgf)	No significance (P-Value = 0.847)	No significance (P-Value = 0.449)	No significance (P-Value = 0.631)
Seam efficiency (%)	No significance (P-Value = 0.847)	No significance (P-Value = 0.449)	No significance (P-Value = 0.631)
Seam slippage (mm)	No significance (P-Value = 0.134)	No significance (P-Value = 0.424)	No significance (P-Value = 0.299)

Table 7 Preliminary study - seam strength testing (kgf)

Sr No.	Warp + Course	Warp +Wales	Weft + Wales	Weft + Course
1	17	11.5	4.5	9
2	13.5	6	8	7
3	14	6.5	5	7.5
4	17.5	10.5	4.5	15
5	15	13.5	5	13
6	15	14	5	14.5
7	15	10	4	13
8	15	8	4.5	9
9	15	12	5	12
10	14	10	5	13

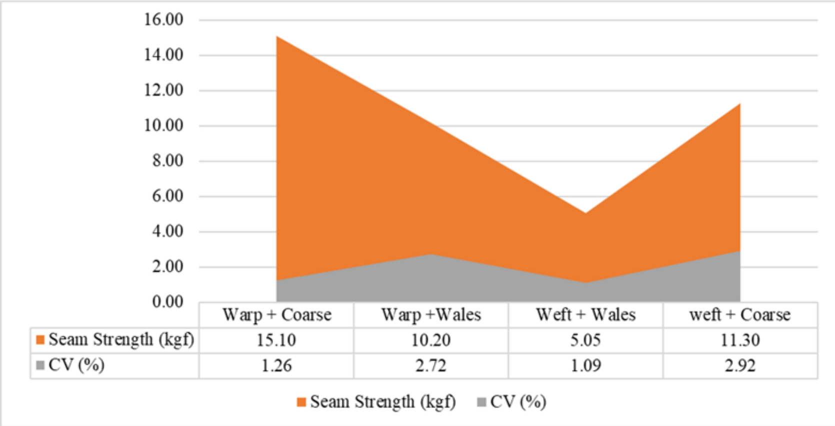


Figure 4 Preliminary study seam strength testing

3.2 Main effects plots

3.2.1 Seam strength

In this test, a specimen is subjected to tension until it reaches the breaking point. The test is conducted using a Fabric Strength Tester or Instron, in accordance with ASTM D1683, which provides guidelines for measuring seam strength in woven fabric. Figure 5 illustrates the main effects of various factors, including seam type, ticket number, and SPI, on seam strength.

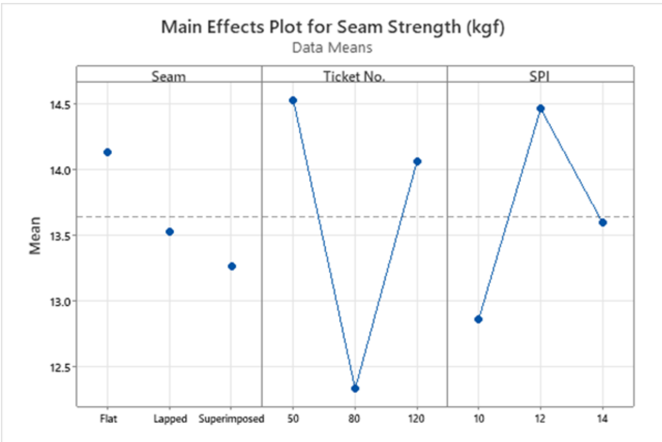


Figure 5 Main effects plot for seam strength (kgf)

Figure 5 depicts the impact of various factors on the seam strength of compound fabric. The findings indicate a notable effect resulting from changes in these factors. The seam strength of the compound fabric reveals significant differences among the samples. Specifically, the study reveals that the flat seam exhibits the highest strength, while the sewing thread with a ticket number of 50 displays the maximum seam strength. Moreover, the sample with 12 stitches per inch demonstrates superior seam strength compared to the samples with 10 and 14 stitches per inch.

3.2.2 Seam efficiency

It is the ratio of seam strength to the fabric strength. The following graph shows the main effect of different factors on the seam efficiency.

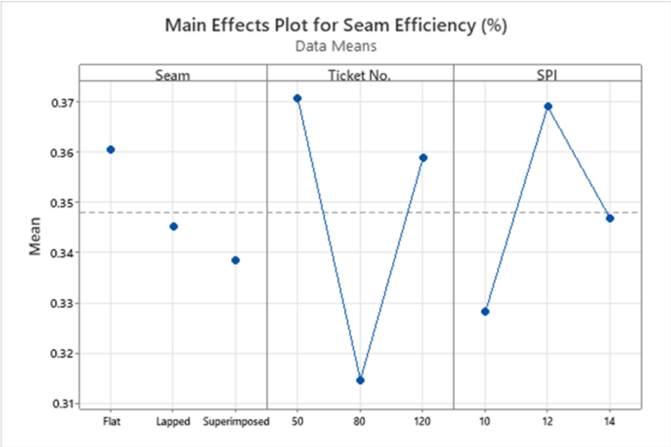


Figure 6 Main effects plot for seam strength (kgf)

Figure 6 illustrates the influence of factors on the seam efficiency of compound fabric. The findings indicate a substantial impact resulting from variations in these factors. Higher values of the factors correspond to improved seam efficiency. The seam efficiency of the compound fabric reveals significant differences among the samples. Specifically, the study demonstrates that the flat seam exhibits the highest seam efficiency, while the sewing thread with a ticket number of 80 displays maximum efficiency. Furthermore, the sample with 12 stitches per inch demonstrates superior seam efficiency compared to the samples with 10 and 14 stitches per inch.

3.2.3 Seam opening

Seam slippage is a tendency for a seam to open due to the application of a force perpendicular to the seam direction.

Figure 7 presents the impact of factors on the seam efficiency of compound fabric. The findings reveal a substantial effect resulting from variations in these factors. It is observed that higher factor values lead to an increased opening of the seam, which adversely affects seam quality. Conversely, lower values of seam slippage/opening indicate better seam quality. The seam slippage results of the compound fabric demonstrate significant differences among the samples. The study highlights that both the flat seam and lapped seam exhibit superior seam quality, as evidenced by lower values of seam slippage. On the other hand, the sewing thread with a ticket number of 50 shows higher seam slippage, making it more prone to slipping. In contrast, the sewing thread with a ticket number of 120 demonstrates a lower seam slippage value, indicating better resistance to slipping. Additionally, the sample with 14 stitches per inch yields the best results in terms of seam slippage strength.

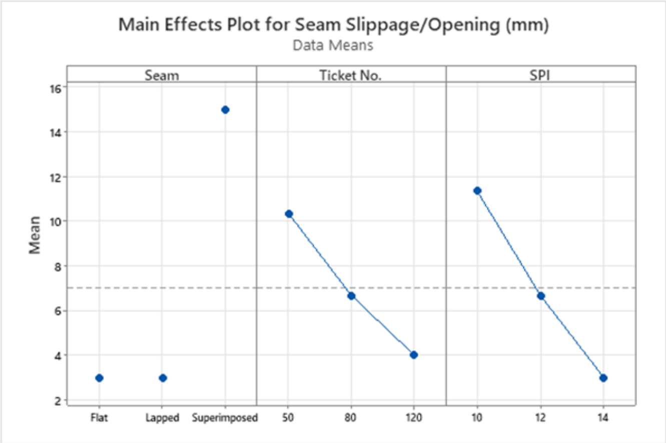


Figure 7 Main effects plot for seam slippage/opening (mm)

3.2.4 Seam puckering

Seam puckering refers to the undesired gathering or wrinkling of a seam during or after sewing, as well as after laundering, leading to an unacceptable appearance. In terms of fabric sewability, the absence of seam puckering is an indicator of good quality. Our observations indicate that no instances of seam puckering occurred during the stitching process or after the completion of stitching.

3.3 Optimization

Based on the results discussed in 3.2, an optimization process was conducted to identify the sample that yielded the best results across all properties, including seam strength, seam efficiency, and seam slippage/opening. Table 8 shows the response optimization outcomes for various parameters and provides corresponding solutions.

3.3.1 Response Optimization

Table 8 Optimization requirements

Response	Goal	Lower	Target	Upper	Weight	Importance
Seam Slippage /opening (mm)	Minimum		1.0	25	1	1
Seam Efficiency (%)	Maximum	0.28	0.4		1	1
Seam Strength (kgf)	Maximum	11.00	15.8		1	1

Table 9 Optimized parameters

Seam	Ticket No.	SPI	Seam slippage/ opening (mm) Fit	Seam Efficiency (%) Fit	Seam Strength (kgf) Fit	Composite Desirability
Flat	50	12	6	0.404195	15.8444	0.988937

Table 9 shows the solution for optimization of sewability of It is inferred that the flat seam of sewing thread having ticket number 50 with 12 stitches per inch sample shows the best results in case of all the properties like seam strength, seam efficiency and seam slippage/opening.

Conclusion

In conclusion, this investigation focused on studying the sewability of compound fabrics and optimizing its performance. The following key conclusions have been drawn: The ticket number has the most significant impact on seam strength and seam efficiency, surpassing the effects of SPI (stitches per inch) and seam type. The warp-course combination of woven and knitted fabric demonstrated the highest strength among the specimens tested. Overall, the specimens with a flat seam, using a sewing thread with a ticket number of 50 and a stitch density of 12 SPI, exhibited favourable properties. Importantly, after combining woven and knitted fabric, no seam puckering was observed, indicating successful integration. These findings provide valuable insights for optimizing the sewability of compound fabrics, leading to improved garment quality and performance in the apparel industry.

Roles of author

Study Conception and Design (R.P, U.P); Experimentation – Collection of data (R.P, U.P); Analysis and Interpretation of Results (R.P, U.P, A.H); Writing the Original Draft (R.P.); Writing-review and Editing (R.P., A. H.); Over all supervision (U.P.).

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Visibility aids for pedestrian safety at night: Review and recommendations for future studies

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Abstract

There are increased pedestrian accidents at night-time as compared to daytime. This has resulted in the manufacture of visibility aids to improve the recognition and visibility of pedestrians at night-time. In this study, we identified and reviewed the top thirteen related studies in this field to understand their findings under three themes; visibility aids for pedestrian recognition; factors affecting driver's recognition performance, and influences of pedestrian visibility. Findings revealed that retro-reflective clothing with biomotion configurations improved pedestrians' visibility, even though their attitude towards its usage, driver's age and illumination under different conditions influenced their recognition ability at night time. Based on these findings, we propose key recommendations for future studies to help enhance the protection, safety, visibility, and recognition of pedestrians on the road at night-time.

Keywords: Visibility aids, Pedestrian safety, Night-time

1 Introduction

Safety on the road has remained an important feature for every stakeholder in the World. A report on *Save lives: a road safety technical package* by the World Health Organization (2017) revealed that nearly half of the total road traffic crashes and deaths are pedestrians, motorcyclists, and cyclists. Most of these pedestrian deaths were recorded at night-time (Hu and Cicchino 2018). This recurring phenomenon has influenced the manufacture of visibility aids like retroreflective materials to improve the conspicuity of a pedestrian on the road. In this paper, we argue based on gathered studies, that visibility aids are important for use by pedestrians on the road at night-time to help limit related injuries and deaths. To identify the related studies on visibility aids for pedestrian safety at night-time and to make the necessary recommendations, we draw upon existing literature using the Scopus database.

2 Methodology and Theme identification

The Scopus database was used to obtain research publications with search block ("visibility aids" OR "retro-reflective" OR "retroreflective" OR "high visibility clothing") AND ("bicyclist" OR "cyclist" OR "pedestrians"). This related search was conducted on April 12, 2023. This produced a total output of 102 publications comprising different documents, languages, and year types amongst others. Scopus database is used to obtain bibliographic data because of the data analysis accuracy and the housing of a wide range of publications (Falagas, Pitsouni, Malietzis, and Pappas 2008). Publication output was further restricted to the type of language (English), resulting in an output of 100. The "cited by (highest)" option in the dropdown menu of the "Sort on" tab was selected to provide the publications highly cited by other researchers and studies. The study further identified thirteen (13) publications (see Table 1) with citations ≥ fifty (50). This selection criteria were to understand the scope, objectives, and findings of these publications which have received several citations from other researchers in the field. Subsequently, the selected studies were put into a timeline diagram (Figure 1) to identify the publication trend and the related themes for further discussion and analysis.

2.1 Theme 1: Visibility aids for pedestrian recognition

Visibility aids were developed to improve the visibility, detection and recognition of road users especially pedestrians by drivers at nighttime. This imperatively aims at limiting accidents with approaching vehicles and improving driver response rate on the road. To clearly understand this, a study by Olson, Halstead-Nussloch, and Sivak (1981) developed different markings on motorcycles and evaluated their conspicuity for drivers. Results revealed that three out of four motorcycle accidents occurred at nighttime hence road users should use helmet covers and retroreflective vests for night-time conspicuity. The use of retro-reflective tags as compared to dark clothing doubled the visibility distance of pedestrians at nighttime, as reported in a study by Shinar (1984). Even at low light beams, the visibility of the pedestrian with retro-reflective tags was still very good. Confirming this, a study by Owens, Antonoff, and Francis (1994) reported that, retro-reflective markings in biological motion improved the visibility of the pedestrian at night-time. Similar findings were reported by Luoma, Schumann, and Traube (1996), even though “the retro-reflective markings attached to the limbs led to significantly longer (about 60–80%) recognition distances than when these retro-reflective markings were attached to the torso”. Kwan and Mapstone (2004) in their study concluded that the use of visibility aids and biomotion markings improved the detection, recognition, and safety of cyclists and pedestrians on the road at night time whereas the use of fluorescent colours (orange and yellow) improved visibility in daytime.

Table 1 – The selected thirteen publications with citations ≥ fifty (50)

Authors	Title	Year	Journal	Cited by
Wood J.M., Tyrrell R.A., Carberry T.P.	Limitations in drivers' ability to recognize pedestrians at night	2005	Human Factors	114
Wood J.M., Owens D.A.	Standard measures of visual acuity do not predict drivers' recognition performance under day or night conditions	2005	Optometry and Vision Science	98
Wood J.M., Lacherez P.F., Marszalek R.P., King M.J.	Drivers' and cyclists' experiences of sharing the road: Incidents, attitudes and perceptions of visibility	2009	Accident Analysis and Prevention	90
Kwan I., Mapstone J.	Interventions for increasing pedestrian and cyclist visibility for the prevention of death and injuries	2009	Cochrane Database of Systematic Reviews	90
Owens D.A., Wood J.M., Owens J.M.	Effects of age and illumination on night driving: A road test	2007	Human Factors	83
Walker I., Garrard I., Jowitt F.	The influence of a bicycle commuter's appearance on drivers' overtaking proximities: An on-road test of bicyclist stereotypes, high-visibility clothing and safety aids in the United Kingdom	2014	Accident Analysis and Prevention	67
Thornley S.J., Woodward A., Langley J.D., Ameratunga S.N., Rodgers A.	Conspicuity and bicycle crashes: Preliminary findings of the Taupo Bicycle Study	2008	Injury Prevention	65
Owens D.A., Antonoff R.J., Francis E.L.	Biological motion and nighttime pedestrian conspicuity	1994	Human Factors	62
Kwan I., Mapstone J.	Visibility aids for pedestrians and cyclists: A systematic review of randomised controlled trials	2004	Accident Analysis and Prevention	58
Luoma J., Schumann J., Traube E.C.	Effects of retroreflector positioning on night-time recognition of pedestrians	1996	Accident Analysis and Prevention	58
Tyrrell R.A., Wood J.M., Chaparro A.,	Seeing pedestrians at night: Visual clutter does not mask biological motion	2009	Accident Analysis and Prevention	56

Carberry T.P., Chu B.-S., Marszalek R.P.				
Shinajr D.	Actual versus estimated night-time pedestrian visibility	1984	Ergonomics	50
Olson P.L., Halstead Nussloch R., Sivak M.	The effect of improvements in motor cycle/motor cyclist conspicuity on driver behavior	1981	Human Factors	50

Note: Information retrieved from Scopus

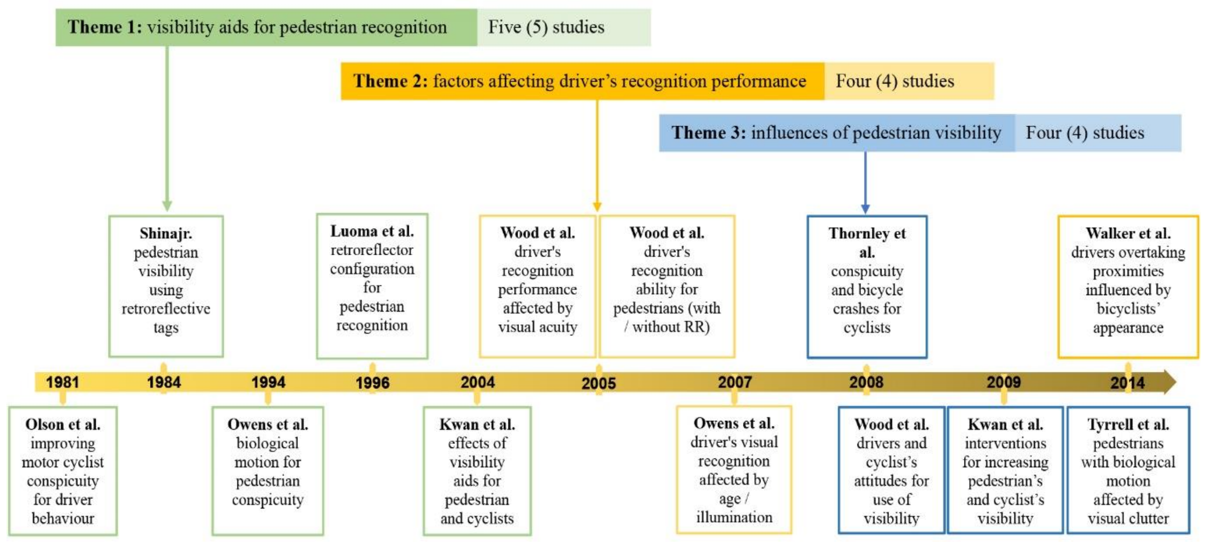

Figure 1. Timeline and identified related themes of research publications

2.2 Theme 2: Factors affecting driver's recognition performance

Understanding the driver's visual or vision performance at night time is imperative for a quick response and recognition by the driver of pedestrians on the road. As such a study was conducted by Wood and Owens (2005) to understand the effects of luminance conditions on the visual acuity of drivers. Findings concluded that visibility and recognition performance under low light conditions was seriously degraded in drivers for all ages at night time but was however greater in older drivers. Pedestrians with retro-reflective clothing in full biomotion configuration are more recognised under high beam by drivers (both young and old) as compared to about 5% recognition ability by drivers under low beam when pedestrians wear dark (black) clothing at night-time (Wood, Tyrrell, and Carberry 2005). Further findings in a study by Owens, Wood, and Owens (2007) confirmed that age and illumination influenced driver recognition performance at night time. Here, both younger and older drivers can recognise pedestrians with retro-reflective markings at the limb joint area. Older drivers were however cautious under low beam conditions on the road at night-time due to their diminished visual recognition. The type of clothing worn by bicyclists according to Walker, Garrard, and Jowitt (2014) did not influence drivers' overtaking activity on the road at night time. This phenomenon could influence the recurring collisions with bicyclists on the road leading to related injuries and associated deaths.

2.3 Theme 3: Influences of pedestrian visibility

As mentioned earlier, pedestrian visibility is imperative to limit any related accidents or collisions with the moving vehicle. However certain conditions have influenced their visibility on the road at night-time. In a study by Thornley et al. (2008), findings revealed that low cyclist conspicuity at night time increased crash-related injuries which subsequently led to time off from work. Cyclist's attitude towards the use of visibility aids is another factor influencing their conspicuity and driver's recognition ability on the road at night time (Wood, Lacherez, Marszalek, and King 2009). Study findings by Tyrrell et al. (2009) proved that visual clutter in the environment did not influence the conspicuity of pedestrians wearing retro-reflective clothing in biomotion configurations. To improve pedestrian visibility, Kwan and Mapstone (2009) proposed the use of visibility aids e.g., fluorescent materials in orange, red and yellow colours, and biomotion markings of retroreflective materials. These materials are combined effectively to produce high-visibility clothing which improves day and night time visibility of the pedestrian.

3 Implications and recommendations for future studies

The present study provided vital information on visibility aids for pedestrian safety at night-time. Findings from the top cited studies revealed that retro-reflective marking on clothing improved the visibility and recognition of pedestrians. It is thus recommended for the incorporation of highly retro-reflective threads for fabric production (either woven or knitted), to make the wearers more visible or maximize pedestrian conspicuity to drivers at night-time. Future studies should investigate the integration of smart technologies to produce dynamic interactive clothing systems that produce lighting effects under low or dark conditions hence making the pedestrian visible.

Subsequent findings revealed that age and illumination resulted in the poor visual ability of the drivers at night time hence contributing to pedestrian accidents. It is thus recommended for future studies to develop intelligent warning and transport systems for drivers. These systems should effectively detect the location of pedestrians at a long distance and provide real-time location data of pedestrians to drivers for quick response and recognition. Also, advanced night vision technology for drivers would help warn and alert drivers at night to prevent any collision with pedestrians. A more advanced technology of smart glasses development could improve the vision of the drivers and provide real-time data on the location of pedestrians on the road.

Pedestrian attitude towards the use of visibility aids was one of the factors revealed by the studies that influenced their conspicuity at night time. As such, social media awareness, education for pedestrians and drivers, and strict policies on the use of visibility aids are necessary to improve safety on the road. Future studies should be conducted on developing effective frameworks and intervention mechanisms for collaboration by relevant stakeholders. Studies on understanding the factors influencing the use of these visibility aids would help in the framework development and be a good source for clothing manufacturers to produce comfortable safety wear for pedestrians.

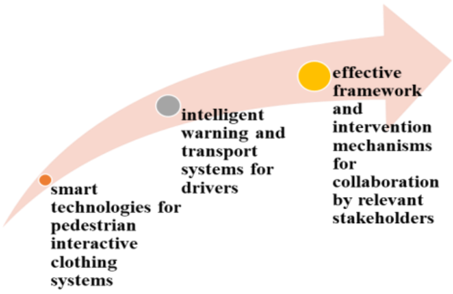

Figure 2. Recommendations for future research studies

Conclusion

Promoting and maintaining the use of visibility aids by pedestrians at night is the ideal approach to improving safety on the road. This coupled with road lighting systems and technologies for drivers' vision at night-time will help them recognise the pedestrian on time and limit any collision that may result in injuries and possible deaths. Continuous campaigns and awareness creation by all stakeholders would help ensure pedestrian-free accidents with moving vehicles on the road since every life is important on the road.

Roles of author

Conceptualization, Analysis and Interpretation of Results, Writing (R.K.S); Review, Editing and Overall supervision (S.J).

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Conflict of interest

The author declares that there is/are no conflicts of interest.

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Investigation of hybridization effect on the mechanical properties of Glass-Agave Americana leaf fibre reinforced hybrid composites

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Abstract

This study investigates the effect of intra-ply hybridization on the mechanical properties of Glass-Agave Americana leaf fibre reinforced hybrid composites. Intra-ply hybridization involves blending the two types of fibres within a single layer, resulting in a novel composite material. The composites were fabricated using a hand-layup technique, and a 33 factorial experiment was designed based on Taguchi's L9 orthogonal array. Three factors were considered with three levels each: the blend ratio of Glass-Agave Americana leaf fibres (10:90, 50:50, 90:10), the fibre volume fraction (0.1, 0.25, 0.40), and the areal density of the reinforcement agent (250, 400, 550 gm/cm^2). The mechanical properties of the composites were evaluated through tensile, flexural, and impact tests. The results demonstrate that the hybridization of Glass-Agave Americana leaf fibres significantly influences the properties of the composites. Blend ratio, fibre volume fraction, and areal density of the reinforcement agent has considerable influence on evaluated mechanical characteristics of composites.

Hybridization index was calculated based on the rule of hybrid mixtures. The results indicate that the hybridization index values for tensile strength, elongation, flexural strength, and impact strength range from 1.01 to 1.20, demonstrating the positive influence of hybridization on the mechanical properties of the composites. The findings of this study highlight the importance of intra-ply hybridization in improving the mechanical properties of Glass-Agave Americana leaf fibre reinforced hybrid composites.

Keywords: RoHM, Inter-ply Hybridization, Leaf fibres, Mechanical properties

1 Introduction

Intra-ply hybrid textile composites have gained significant attention in recent years due to their potential for improving the mechanical properties of composite materials (Swolfs, Gorbatikh, and Verpoest 2014). The combination of different fibre types within a single layer offers a unique opportunity to enhance specific properties, such as strength, stiffness, and impact resistance.

Agave Americana leaf fibres have garnered interest in various industries as a sustainable and renewable reinforcement material. These natural fibres possess properties such as high strength, low density, and biodegradability. On the other hand, glass fibres are widely known for their exceptional mechanical properties, including high tensile and flexural strength. By combining these two fibre types in hybrid composites, it is expected to achieve synergistic effects that can enhance the overall performance of the material.

The rule of hybrid mixtures is a fundamental concept employed in this study to understand and predict the mechanical behaviour of hybrid composites. It establishes that the properties of a hybrid composite are influenced by the individual properties of its constituents and their respective volume fractions. The hybrid effect is described as an increase in the apparent failure strain of a low elongation (LE) fibre in a hybrid composite compared to the failure strain of a non-hybrid composite reinforced with LE fibre. Another description of the hybrid by which we could get more information is A divergence from the simple rule of mixes (Swolfs, Gorbatikh, and Verpoest 2014). By considering different blend ratios, fibre volume fractions, and areal densities of the reinforcement agent, the rule of hybrid mixtures enables us to systematically investigate the effect of hybridization on the mechanical properties of the composites.

Understanding the hybridization effect is crucial for optimizing the design and manufacturing of composite materials with tailored properties. The combination of Agave Americana leaf fibres and glass fibres offers a promising opportunity to develop lightweight, eco-friendly composites with improved strength and performance characteristics (Swolfs, Gorbatikh, and Verpoest 2014, Mallick 2007). By comprehensively studying the mechanical properties of intra-ply hybrid composites, this research aims to provide valuable insights into the hybridization effect and guide the development of advanced composite materials for various engineering applications.

This research focuses on investigating the effect of intra-ply hybridization on the mechanical properties of Glass-Agave Americana leaf fibre reinforced composites.

1.1 Rule of hybrid mixtures

The mixing rule is utilised to manufacture hybrid fibre reinforced polymer composites. The Rule of Hybrid Mixtures (RoHM) is derived by considering the hybrid composite made by two single composite systems having no interaction between them. The elastic modulus of the hybrid composite (E_{hc}) may be calculated using the RoHM equation as follows:

$$E_{hc} = E_{c1}V_{c1} + E_{c2}V_{c2}$$

where $V_{c1}$and V_{c2} the relative hybrid volume fraction of the first and the second composite system, respectively. The following equations are valid for the system considered to derive the RoHM.

$$V_{c1} + V_{c2} = 1$$

$$V_{c1} = \frac{V_{f1}}{V_f}, V_{c2} = \frac{V_{f2}}{V_f}$$

$$V_f = V_{f1} + V_{f2} \text{ and } W_f = W_{f1} + W_{f2}$$

$$V_{f1} = \rho_c \frac{W_{f1}}{\rho_{f1}}, V_{f2} = \rho_c \frac{W_{f2}}{\rho_{f2}}$$

where, V_f is the total reinforcement volume fraction and W_f is the weight of the fibre. V_{c1} and V_{f1} are the comparative volume fraction first reinforcement and fibre. V_{c2} and V_{f2} are the relative volume fraction second reinforcement and fibre. ρ_f and ρ_c are the density of the fibre and composites (Mallick 2007).

1.2 Hybridization index

The hybridization index values provide a quantitative measure of the performance enhancement resulting from the hybridization of two different reinforcement agents. These values are calculated by dividing the obtained test results by the rule of hybrid mixtures.

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$$Hybridization\ Index = \frac{\text{Average of Obtained Test Results}}{\text{Results by the Rule of Hybrid Mixtures}}$$

If the hybridization index value for any property is greater than one, then that indicates the positive influence of hybridization on that property of the composites.

2 Materials and Methods

The materials used in this study consisted of the following components:

1. **Reinforcement Agents:** Agave Americana leaf fibres were utilized as a natural reinforcement agent. These fibres possess properties such as high strength, low density, and biodegradability. Glass fibres were also used as reinforcement agent.
2. **Matrix Material:** Isophthalic Polyester Resin (Mechanical Grade) served as the matrix material, providing the necessary binding and structural integrity to the composite.
3. **Additives:** Cobalt Napthanate was used as an accelerator to enhance the curing process of polyester resin. Methyl Ethyl Ketone Peroxide acted as a catalyst, initiating the crosslinking reaction of the polyester resin.

Agave Americana leaf fibres and glass fibres were blended within a single layer, ensuring a homogeneous mixture throughout the composite. The Agave Americana leaf fibres and glass fibres were used in the form of nonwoven mats for ease of handling and uniform distribution within the composite. Agave Americana fibres were blended with Glass fibres in blow room and formed into homogeneous web using card and converted to mat in Trutzschler needle punching line. Blend ratio of Glass fibres to Agave Americana leaf fibres (10:90, 50:50, 90:10) was maintained during manufacturing of needle punched nonwoven fabric. While manufacturing the nonwoven fabric, its overall areal density was also changed and set as per the requirement. These manufactured nonwoven samples were used as reinforcement agents to manufacture the composite.

A Taguchi L9 orthogonal array design was employed for sample manufacturing. This design allowed for the investigation of three factors, each with three levels, resulting in a total of nine unique combinations. The factors considered were the blend ratio of Glass fibres to Agave Americana leaf fibres (10:90, 50:50, 90:10), the fibre volume fraction (0.1, 0.25, 0.40), and the areal density of the reinforcement agent (250, 400, 550 gm/cm^2). Sampling design according to Taguchi L9 orthogonal array design has been shown in Table 1.

Table 1 Taguchi L9 orthogonal array design

Sr. No.	Blend Ratio (G: A)	Areal Density (gm/cm^2)	Fibre Volume Fraction
1	10:90	250	0.1
2	10:90	400	0.25
3	10:90	550	0.4
4	50:50	250	0.25
5	50:50	400	0.4
6	50:50	550	0.1
7	90:10	250	0.4
8	90:10	400	0.1
9	90:10	550	0.25

2.1 Manufacturing of hybrid composites

The manufacturing process of the Glass-Agave Americana leaf fibre reinforced hybrid composites involved the following steps:

1. **Mold preparation:** A mold with the desired dimensions (450mm x 450mm) and surface finish was prepared for sample fabrication. The mold was thoroughly cleaned and coated with a mold release agent to ensure easy removal of the cured composite samples.
2. **Layering and blending:** The Agave Americana leaf fibres and glass fibres, in the form of nonwoven mats, were layered within the mold according to the predetermined blend ratios specified by the Taguchi L9 orthogonal array design.
3. **Matrix material preparation:** The isophthalic polyester resin (mechanical grade) was mixed with the appropriate amount of accelerator (2% cobalt napthanate) and catalyst (3% methyl ethyl ketone peroxide). The mixing process was carried out meticulously to achieve a uniform dispersion of the accelerator and catalyst within the resin.
4. **Impregnation and consolidation:** The mixed polyester resin was carefully poured onto the layered reinforcement agents within the mold, allowing the resin to impregnate the nonwoven fibre mats. This ensured proper wetting and bonding between the fibres and the matrix. Consolidation was performed to eliminate any trapped air or voids within the composite. 0.22 MPa Pressure was applied using a roller or suitable consolidation tool to enhance the interfacial adhesion between the fibres and the matrix.
5. **Curing:** The composite samples were cured for 24 hours at room temperature. The curing process involved subjecting the samples to controlled temperature and duration, allowing the resin to undergo crosslinking and achieve the desired mechanical properties.

6. **Demoulding and trimming:** After the curing process was complete, the cured composite samples were carefully taken out from the mold. The mold release agent facilitated easy removal with minimal damage to the samples. Excess material or flash around the edges of the samples was trimmed off to obtain the final desired dimensions (400mm x 400mm).

2.2 Evaluation

All the manufactured samples were cut into the appropriate dimensions for the tensile strength (ASTM D3039), flexural strength (ASTM D790), and impact strength (ASTM D256) tests. All the tests were conducted in standard atmospheric conditions. All these tests were conducted on universal tensile machine with 1500kN capacity.

3 Results and discussion

Table 2 represents the mechanical characteristics of all 9 Intraply hybrid composites. Whereas Table 3 represents the hybridization effect in all nine samples for respective characteristics.

Table 2 Mechanical characteristics of intra ply hybrid composites

Sr. No.	Blend Ratio (G: A)	Areal Density (gm/cm^2)	Fibre Volume Fraction	Tensile Strength (MPa)	Elongation (%)	Flexural Strength (MPa)	Impact Strength (J/mm^2)
1	10:90	250	0.1	140.26	4.99	76.36	2.30
2	10:90	400	0.25	179.87	3.71	98.92	2.86
3	10:90	550	0.4	263.84	2.93	140.85	4.29
4	50:50	250	0.25	195.53	3.72	101.41	3.06
5	50:50	400	0.4	242.51	2.63	137.69	3.99
6	50:50	550	0.1	259.75	2.86	142.83	4.28
7	90:10	250	0.4	262.35	2.49	143.96	4.46
8	90:10	400	0.1	248.64	2.53	138.43	4.10
9	90:10	550	0.25	331.08	1.91	179.53	5.59

G: Glass Fibre, A: Agave Americana Leaf Fibre

Table 3 Hybridization index

Sr. No.	Blend Ratio (G: A)	Areal Density (gm/cm^2)	Fibre Volume Fraction	Tensile Strength (MPa)	Elongation (%)	Flexural Strength (MPa)	Impact Strength (J/mm^2)
1	10:90	250	0.1	1.02	0.91	1.01	1.02
2	10:90	400	0.25	1.09	0.90	1.09	1.06
3	10:90	550	0.4	1.20	0.85	1.17	1.19
4	50:50	250	0.25	1.08	0.89	1.02	1.03

5	50:50	400	0.4	1.12	0.84	1.16	1.13
6	50:50	550	0.1	1.01	0.97	1.01	1.02
7	90:10	250	0.4	1.15	0.83	1.15	1.20
8	90:10	400	0.1	1.03	1.00	1.04	1.04
9	90:10	550	0.25	1.03	0.90	1.02	1.06

3.1 Tensile strength

Tensile strength is the maximum stress that a material can withstand while being stretched or pulled before breaking. Figure 1 represents the main effects plot for tensile strength. In figure 1, X axis represents the factors and Y axis represents the data means.

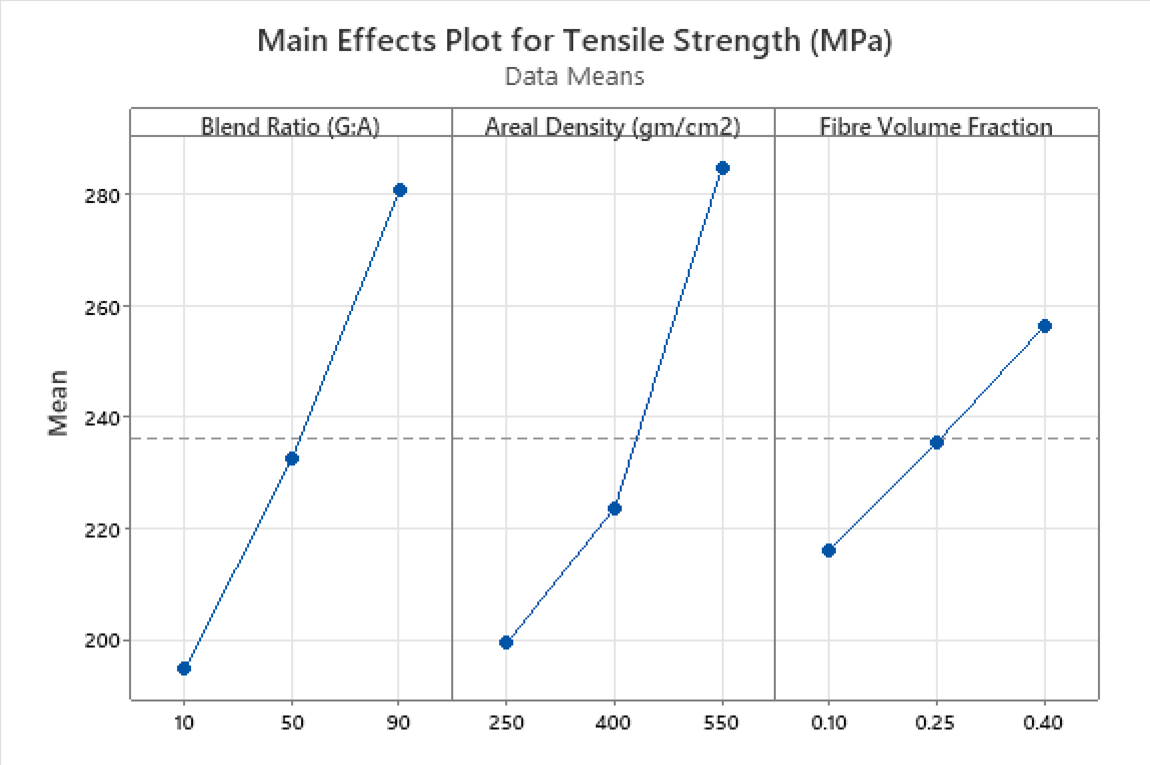

Figure 1 Main effects plot for tensile strength

The blend ratio refers to the proportion of Glass Fibres to Agave Americana Leaf Fibres in the composite samples. The results indicate that the blend ratio has a significant impact on the tensile strength of the composites. Tensile strength of composite increases as amount of glass fibre increases in reinforcement agent. This can be attributed to the high tensile strength characteristics of glass fibres, which contribute to the overall strength of the composites.

The areal density of the reinforcement agent refers to the mass of the fibres per unit area. The results show that the areal density of the reinforcement agent has a noticeable effect on the tensile strength of the composites. An increase in the areal density of intra ply hybrid textile reinforcement tends to enhance the tensile strength of the composites. This can be attributed to the increased fibre content, leading to more load-bearing capacity and improved interfacial adhesion between the fibres and the matrix.

The fibre volume fraction represents the volume percentage of fibres in the composite. The results demonstrate that the fibre volume fraction plays a crucial role in determining the tensile strength of the composites. An increase in the fibre volume fraction leads to an improvement in the tensile strength. This is due to the increased fibre content, resulting in enhanced load-bearing capability and improved stress transfer between the fibres.

The hybridization index for tensile strength reveals that the mechanical property is influenced by the combination of factors studied. The blend ratio, areal density, and fibre volume fraction all contribute to the overall tensile strength of the composites. Higher hybridization indices indicate improved tensile strength, suggesting that specific combinations of these factors have a synergistic effect on reinforcing the composite structure. This suggests that carefully selecting the appropriate blend ratio, areal density, and fibre volume fraction can lead to composites with enhanced tensile strength.

3.2 Elongation

Figure 3 represents the main effects plot for tensile strength. The blend ratio has shown a noticeable effect on the elongation properties of the composites. The results reveal that changing the blend ratio can significantly influence the elongation behaviour of the materials.

It is observed that composites with higher proportions of Agave Americana Leaf Fibres tend to exhibit higher elongation values. This can be attributed to the inherent flexibility and ductility of Agave Americana Leaf Fibres, which allow for a greater capacity to deform before fracture occurs. On the other hand, as the proportion of Glass Fibres increases, the elongation values decrease due to the inherently brittle nature of glass fibres.

The results demonstrate that the areal density can influence the elongation behaviour to some extent. Composites with higher areal densities tend to exhibit lower elongation values. This can be attributed to the increased fibre content, which leads to a more rigid structure and reduced ability to deform.

The fibre volume fraction has a significant impact on the elongation properties. The results indicate that an increase in the fibre volume fraction results in a decrease in elongation. This behaviour can be attributed to the increased fibre content, which introduces stiffer elements into the composite matrix, limiting the material's ability to deform.

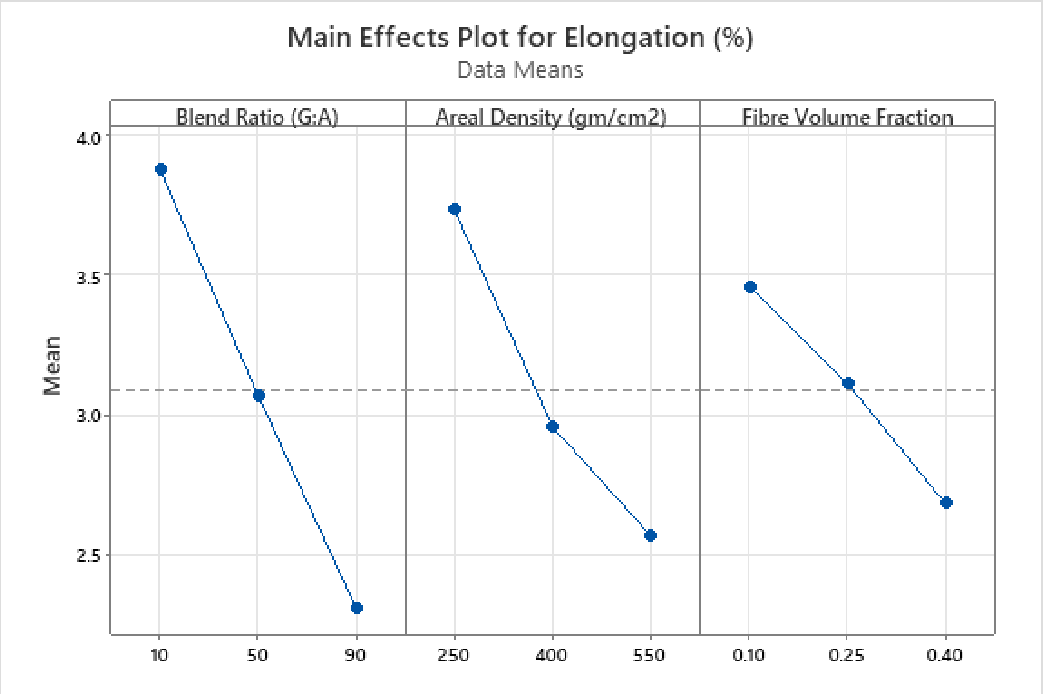

Figure 2 Main effects plot for elongation

The hybridization index for elongation demonstrates the effect of the blend ratio, areal density, and fibre volume fraction on the composite's ability to deform under tensile stress. The results indicate that certain combinations of these factors can influence elongation positively, resulting in improved ductility and flexibility. However, it is important to note that some combinations may lead to reduced elongation. This highlights the need for careful optimization of the factors to balance strength and ductility, depending on the specific application requirements.

3.3 Flexural strength

Flexural strength is the maximum stress that a material can withstand while being bent before breaking. The flexural strength of composite samples was determined according to ASTM D790.

The blend ratio has a significant impact on the flexural strength of the composites. The results indicate that as the proportion of Glass Fibres increases relative to Agave Americana Leaf Fibres, the flexural strength exhibits an upward trend. This can be attributed to the high stiffness and rigidity of glass fibres, which contribute to the overall strength and resistance to bending of the composites.

An increase in the areal density leads to enhanced flexural strength. This is attributed to the increased fibre content, resulting in improved load-bearing capacity, and enhanced interfacial adhesion between the fibres and the matrix. The additional fibres function as reinforcement, distributing and resisting applied loads more effectively.

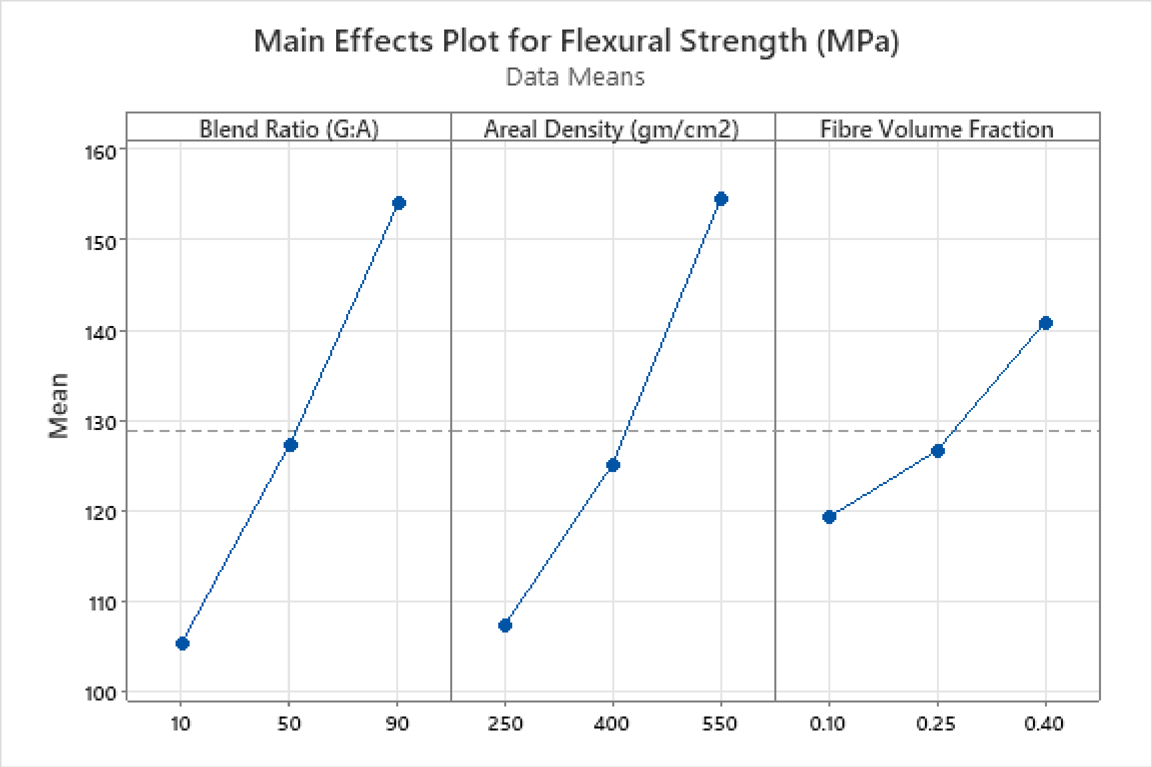

Figure 3 Main effects plot for flexural strength

The fibre volume fraction plays a crucial role in determining the flexural strength of the composites. The results demonstrate that an increase in the fibre volume fraction leads to an improvement in flexural strength. This is attributed to the increased fibre content, which enhances the structural integrity and load-bearing capabilities of the composites. The fibres distribute the applied load and effectively resist bending forces, resulting in higher flexural strength.

The hybridization index for flexural strength reflects the combined influence of the blend ratio, areal density, and fibre volume fraction on the composite's resistance to bending. Higher hybridization indices indicate enhanced flexural strength, suggesting that specific combinations of these factors can effectively reinforce the composite structure and improve its ability to withstand bending loads.

3.4 Impact strength

Impact strength is the ability of a material to absorb energy when it is subjected to an impact load. Impact strength of composite samples were determined according to ASTM D256. Figure 5 represents the main effects plot for impact strength.

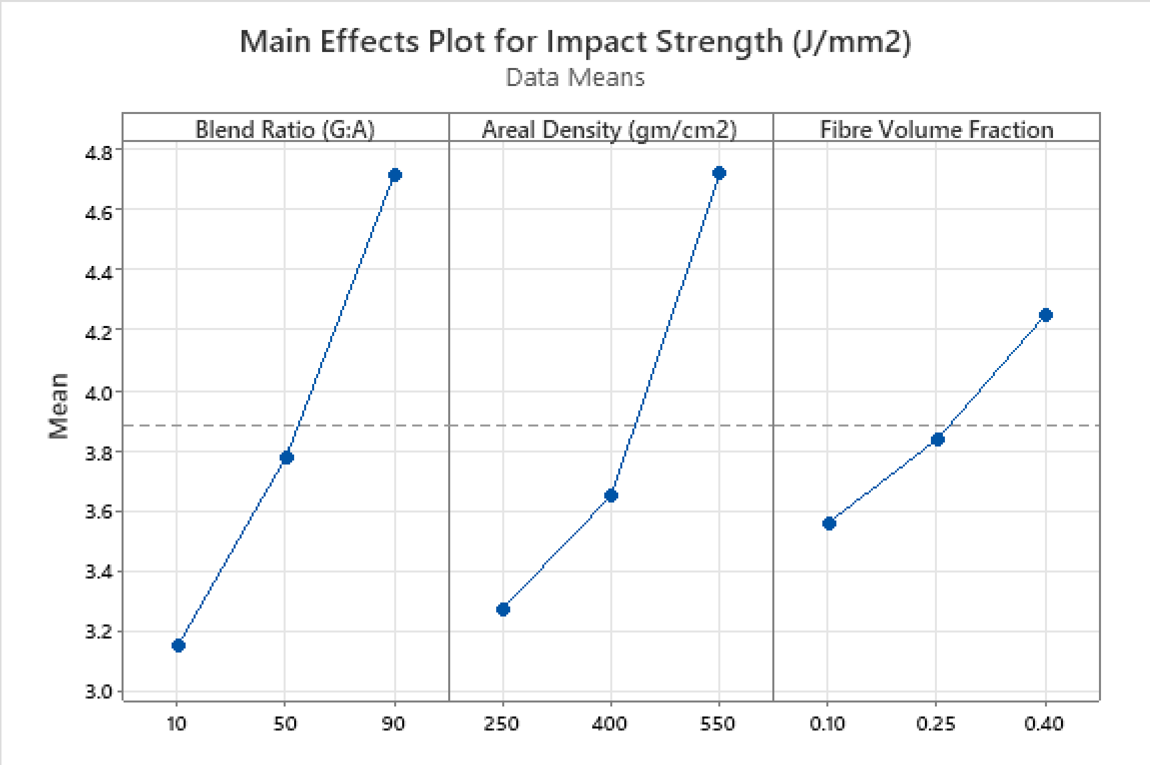

Figure 4 Main effects plot for impact strength

The blend ratio plays a significant role in determining the impact strength of the composites. The results indicate that the impact strength is influenced by changes in the blend ratio. It is observed that composites with higher proportions of Glass Fibres tend to exhibit higher impact strength values. This can be attributed to the superior energy absorption and toughness characteristics of glass fibres, which provide enhanced resistance to impact loading and reduce the propensity for fracture. Conversely, composites with higher proportions of Agave Americana Leaf Fibres typically exhibit lower impact strength values due to their lower stiffness and toughness compared to glass fibres.

The areal density of the reinforcement agent also affects the impact strength of the composites. An increase in the areal density leads to an improvement in impact strength. This can be attributed to the higher fibre content, which enhances the energy absorption capacity and resistance to impact forces. The increased fibre density helps in dissipating and spreading the applied impact energy, resulting in higher impact strength.

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The results demonstrate that an increase in the fibre volume fraction leads to an improvement in impact strength. This is because a higher fibre content contributes to enhanced energy absorption and load-bearing capabilities, effectively resisting impact forces and minimizing fracture initiation.

The hybridization index for impact strength provides insights into the effect of the blend ratio, areal density, and fibre volume fraction on the composite's ability to absorb and withstand impact loads. Higher hybridization indices suggest improved impact strength, indicating that certain combinations of these factors have a synergistic effect on enhancing the composite's resistance to impact forces.

Conclusion

In conclusion, the study investigated the effect of intra-ply hybridization on the mechanical properties of Glass-Agave Americana leaf fibre reinforced hybrid composites. The hybridization index, calculated based on the obtained test results and the rule of hybrid mixtures, provided valuable insights into the influence of numerous factors on the mechanical characteristics of the composites. The key findings are as follows:

1. Higher proportions of Glass Fibres in the blend ratio contributed to improved tensile strength, flexural strength, and impact strength.
2. Increasing the areal density generally led to improved tensile strength, flexural strength, and impact strength up to a certain point.
3. Higher fibre volume fractions generally led to improved tensile strength, flexural strength, and impact strength.
4. The hybridization index indicated that specific combinations of the blend ratio, areal density, and fibre volume fraction could lead to enhanced mechanical properties in the composites.
5. Hybridization index highlighted the synergistic effects of these factors on tensile strength, elongation, flexural strength, and impact strength.

Overall, the study emphasizes the importance of carefully selecting and optimizing the blend ratio, areal density, and fibre volume fraction in hybrid composites to achieve the desired mechanical characteristics. The findings provide valuable insights for designing and tailoring hybrid composites with improved performance and impact resistance for specific applications like riot control shields, car body, bumpers, etc.

Roles of author

Study Conception and Design (A. H., U. P.); Experimentation – Collection of data (A. H.); Analysis and Interpretation of Results (A. H., U.P.); Writing the Original Draft (A. H.); Writing-review and Editing (A.H. R.P.); Over all supervision (U.P.).

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Conflict of interest

The author declares that there is/are no conflicts of interest.

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Development of antibacterial textiles using microencapsulation of Lantana Camara essential oil

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Abstract

Bacterial growth on textiles can cause unpleasant odours, skin irritation problems. Antibacterial fabrics effectively prevent textiles from bacterial attack and even prevent odours while keeping the comfort and hygiene. As a result, antibacterial clothing encapsulated with plant extracts and their essential oils which is widely used in garments, active wear, and healthcare textiles, inhibits the growth of the bacteria.

Lantana Camara, commonly known as wild or red sage, is a flowering ornamental and medicinal plant. Every part of this plant has traditionally been used to treat a variety of diseases. This plant has various properties including antioxidant, antibacterial, anti-inflammatory, antifungal and anticancer activity. However, its properties have been barely studied on textiles. On the other hand, essential oils incorporation into textiles can lead to their evaporation when exposed to air at room temperature since they are volatile and unstable. Thus, instead of traditional pad-dry processes, microencapsulation is a protective method for encapsulating essential oils.

The objective of the present study was to investigate antimicrobial properties of cotton fabrics treated with microencapsulated Lantana Camara essential oil against S. aureus and K. pneumoniae. Microencapsulation was done using complex coacervation technique comprising of Gelatine and Gum Arabic as wall materials. The influence of various parameters, such as the concentration of oil and wall material, and particle size distribution was examined. The results revealed that the encapsulated cotton fabric showed antibacterial percentages of 99% and 94.3% against Staphylococcus aureus and Klebsiella pneumoniae respectively and after washing it retained the properties with 96.8% and 90% antibacterial efficacy against Staphylococcus aureus and Klebsiella respectively.

Keywords: Lantana Camara, Microencapsulation, Antimicrobial clothing, Complex Coacervation, Essential oil

1 Introduction

Lantana camara is an appealing ornamental and flowering shrub with aromatic leaves, bright red to orange to yellow flowers, and blue or violet drupes. It is native to the America and Africa that blooms in tropical and subtropical climates. It is a low-erect, stout, hairy, perennial plant which is a member of the Verbenaceae family. It is also known by other common names including big-sage, red-sage, white-sage, tickberry and wild-sage Girish (2017). The opposite widely ovate leaves offer a potent aroma when crushed. The drupe-like fruit of Lantana camara matures from green to an intense purple colour (Thorat, et al. 2021).

Prior studies have revealed that Lantana camara contains abundant of bioactive compounds including anthocyanins, flavones, flavonoids, coumarins, catechins, isocatechins, lignans alkaloids, triterpenoids, tannin and saponins. It is also a rich source of sesquiterpenes, monoterpenes, and bisabolone derivatives (Girish 2017).

Various parts of Lantana camara plant have been utilised for different medicinal activities. Every single component of this plant has traditionally been used in herbal medicines to treat a variety of diseases around the world such as ulcers, asthma, tumours, measles, swellings, eczema, high blood pressure, jaundice, chicken pox, catarrhal infections, rheumatism, malaria and bronchitis (Girish 2017). Lantana camara has also been used since a very long time to treat and prevent cancer (Srivastava, et al. 2014). The essential oil of different parts of Lantana camara is also considered to be antiseptic, anti-inflammatory, antispasmodic, antihypertensive, antipyretic, carminative and analgesic. Its extracts are said to contain antibacterial, larvicidal and insecticidal properties (Girish 2017). The leaves and flowers of Lantana camara plant are used for treating fever, stomach-aches and flu. The plant's roots are used to treat malaria, skin rashes and rheumatism while the leaves are antiseptic and antibacterial (Baroty, et al. 2014). Therefore, a number of Phyto compounds present in this plant are a contributing factor to several health benefits.

Chronic and infectious disorders developed from bacterial strains have long been a source of concern in the medical community. Undoubtedly, this issue has a significant impact on economic and social/public health considerations. As a result, it is important for the researchers to explore antimicrobials from alternative sources because synthetic antibacterial agents pose a threat to human health (Dubey and Padhy 2013). Chemical based agents commercially available in the market such as silver compounds, triclosan, copper, quaternary ammonium compounds, N-halamine compounds, zinc and other synthetic antibacterial agents are extensively being utilised that can lead to serious health disorders if used in long term (Ravindra, Dinesh and Chandra Sekhara 2021). They are not only harmful to textiles but also to humans and environment.

Therefore, textile sector is constantly focussing on creating and upgrading products that can be effective against several strains of bacteria and can overcome various life-threatening diseases by incorporating antibacterial agents. Antibacterial textile materials are protective materials with properties that can either destroy or inhibit bacterial growth. The inherent properties of the textile fibres, especially cotton being hydrophilic provides ideal conditions for the growth of microorganisms. When the fabric is worn right next to the skin, pathogen cross-infection can also generate bad odour. The microbial attack on textiles can destroy them by losing their elasticity and tensile strength and can also lead to discolouration. As a result, textile materials are given an antibacterial coating to safeguard the wearer and the textile substrate from microorganisms.

A wide spectrum of textile products with antimicrobial finishes has been developed as a result of growing awareness of the hygienic lifestyle of the present generation. Such antibacterial textile materials are used in a variety of applications, including food packaging, air filters, health care and hygiene, water purification equipment’s and sportswear. During the last few years, there has been an increase in public awareness of antibacterial fabrics, as well as an expansion in economic potential (Gulati, Sharma and Sharma 2021). However, the

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substances that are utilised as active ingredients in antibacterial finishing must be efficient, selective against harmful bacteria, safe, non-toxic and biodegradable.

As a result of negative consequences of synthetic antibacterial agents, natural and plant based components have gained a lot of attention. Application of plant extracts and their essential oils have been explored for their antibacterial properties on textiles. In a study by (Dridi, et al. 2021), the chemical composition and antibacterial activity of the essential oils derived from the Syzygium aromaticum and Ceylon cinnamon barks were examined. Sodium hydroxide was utilised as a hardening agent and chitosan as a wall material to form capsules out of the essential oil mixture during coacervation. The results showed that microcapsules adhered to cotton fabric surfaces successfully, transferring antibacterial activity without noticeably altering their characteristics. In another study (Saraf, et al. 2011), the acetone extracts and crude methanolic of Lantana camara was determined against eight fungal strains and thirteen bacterial strains. The largest amount of growth inhibition was seen for Staphylococcus aureus in both solvent extracts. The highest percentage growth inhibition against Alternaria alternata was shown by the fungitoxic spectrum of the test plant's leaf and stem extracts at 1000μgml^{-1} concentration.

Essential oils are liquid compounds extracted from different parts of plant and are described as complex mixtures of volatile secondary lipophilic metabolites. They are highly unstable and are easily influenced by external factors i.e. light, oxygen, humidity and temperature. The use of essential oils in various sectors is hampered by the high volatility and reactivity of these molecules. The microencapsulation approach is frequently employed to maintain the biological and functional properties of these chemicals and to regulate their release in order to get around these restrictions (Sousa, et al. 2022).

The basic concept behind the microencapsulation of substances is the preparation of an emulsion, which involves the substance being microencapsulated (a solid, liquid, or gaseous product) in order to safeguard it and retain its potential. Combinations of solid, liquid, or gaseous encapsulated bioactive compounds may potentially merge, absorb, or disperse throughout the encapsulation process. The prevention of environmental deterioration and the regulated release of particular compounds are the primary objectives. They serve as a barrier; entirely separating the core component from the external environment (Sousa, et al. 2022). The majority of microcapsules have a diameter between 1–1000 μm (Fu and Hu, 15-Temperature sensitive colour-changed composites 2017).

Therefore, the objective of the present study was to encapsulate Lantana camara essential oil and impart antibacterial properties to cotton fabric. The antibacterial finished fabric was developed using complex coacervation technique of microencapsulation technology. Gelatin-Gum Arabic complex encapsulating Lantana camara essential oil was applied to the fabric using pad-dry method and were characterised for their surface morphology. Finally, the antibacterial properties of the finished fabric were evaluated along with the effect of laundering on antibacterial properties of finished cotton was examined.

2 Materials and methods

The cotton fabric (100% cotton and ready for dyeing, plain weave, 152 g/m^2) was sourced from HSPS Textile Pvt Ltd (Harpar Group), New Delhi, India for antibacterial finishing. Gelatine and Gum Arabic were procured from Jai Laxmi Chemicals, Ghaziabad, Uttar Pradesh, India to use and microencapsulate. Lantana camara essential oil was obtained from Kanha Natural Oils, Bahadurgarh, Haryana, India.

2.1 Preparation of microcapsules

According to the methods described by (Specos, et al. 2010), microcapsules of Lantana Camara essential oil were prepared using complex coacervation. Gelatine and Gum Arabic were used as wall material to form the complex of Lantana camara essential oil. Magnetic stirrer was used to prepare oil in water emulsion. Gelatine solution (3% w/v) was prepared in distilled water and different concentrations of Lantana camara essential oil were mixed into the Gelatine solution. Temperature of the dispersion was maintained at 40ºC. Gum Arabic solution (3% w/v) was then poured into the above dispersion drop by drop for complex coacervation to occur and distilled water was added to the dispersion.

After that, the temperature was lowered to below 10ºC, and sodium hydroxide was added to maintain the pH in between 8 and 9. Glutaraldehyde solution (25 %) was added to the above dispersion for hardening of the microcapsules.

2.2 Fabric treatment

The developed microcapsules were applied onto the textile substrate through the pad-dry-cure procedure. After preparing a dispersion of microcapsules (100 g/l) and binder (30 g/l), cotton fabric was dipped into the resulting solution. The treated fabric was dried at 60°C for 5 minutes followed by curing at 120°C and cooled at room temperature, while maintaining a 75±2% wet pick up during padding in the padding mangle (Singh and Sheikh, Multifunctional Linen Fabric Obtained through Finishing with Chitosan-gelatin Microcapsules Loaded with Cinnamon Oil 2021).

2.3 Characterization of microcapsules and finished fabric

The morphological characteristics and the presence of the microcapsules grafted onto the finished fabrics were examined using SEM (Scanning Electron Microscopy) before and after laundering. The size distribution of the microcapsules was also investigated. A small section of fabric was coated with gold using a sample coater set to 25 mA current and 9×10^{-4} Mbar pressure on a carbon tape of the sample holder. The SEM images of finished fabrics were captured using a 10 kV accelerating voltage at various magnifications (Singh and Sheikh, Microencapsulation and its application in production of functional textiles 2020). The size distribution of the microcapsules was also evaluated using SEM.

Fourier-transform infrared (FTIR) spectroscopy was carried out to confirm the chemical constitution of the synthesised microcapsules and to determine the various functional groups present in treated fabrics with microcapsules of gelatine and gum Arabic loaded with Lantana camara essential oil, and untreated fabrics and Lantana camara essential oil. It recognises the various functional groups present in fabric samples as well as changes in functional groups caused by applying the finish to the textile substrate (Singh and Sheikh, Microencapsulation and its application in production of functional textiles 2020).

2.4 Characterization of microcapsules and finished fabric

The antibacterial activity of the finished cotton fabric was evaluated following the AATCC TM 100-2019 standard test method (TM100-2019 2019). Using Staphylococcus aureus and Klebsiella pneumoniae bacterial strains, the finished fabric's ability to inhibit the microbial growth and persistence over a 24-hour contact period was evaluated. The following equation for bacterial count reduction equation was used:

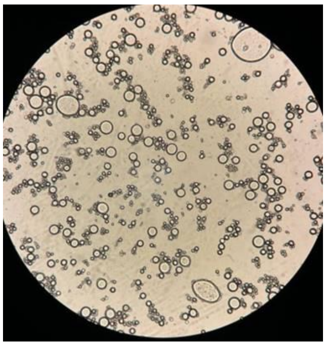
Bacterial count reduction (%) = $(A - C)/A \times 100$

Where: A is the number of bacterial colonies recovered from inoculated control fabric immediately after inoculation. C is the number of bacterial colonies recovered from the inoculated finished fabric after 24 hours of inoculation (Singh and Sheikh, Microencapsulation and its application in production of functional textiles 2020).

3 Results and Discussion

3.1 Characterization of microcapsules and finished fabric

The developed microcapsules were observed under the optical microscope with different magnifications for its shape formation, quantity and construction of wall and core. Figure 1 shows the microcapsules of Gelatine and Gum Arabic loaded with Lantana camara essential oil. The microcapsules were found to be spherical in shape and the quantity of microcapsules increased as well as wall of the capsules became defined and thick with increase in concentration of wall material to 3%.



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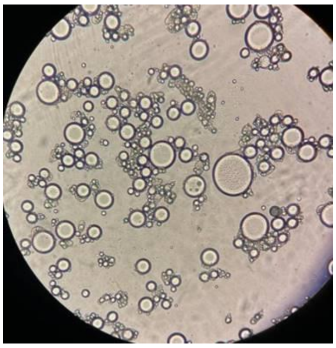


20X

Figure 1 Optical microscope image of microcapsules under 10X and 20X magnification respectively

3.2 SEM analysis

The SEM (Scanning Electron Microscopy) images with morphological analysis of the untreated cotton fabrics and treated cotton fabrics with lantana camara microcapsules are displayed in Figure 2 and 3.

Figure 3 shows the images obtained by SEM which represents the external morphology of the microcapsules after the deposition of microcapsules on the cotton fabric along with the average size distribution. The average size of the microcapsules was found to be 11 μm. It was also observed that the microcapsules are distributed individually without much agglomeration, and they are adhered to the yarn interstices of the cotton fabric as well.

Gelatine and Gum Arabic formed a continuous layer on the Lantana Camara essential oil which may be because of electrostatic interactions between the wall materials. Thus, complex coacervation technique offers a stable oil-in-water emulsion.

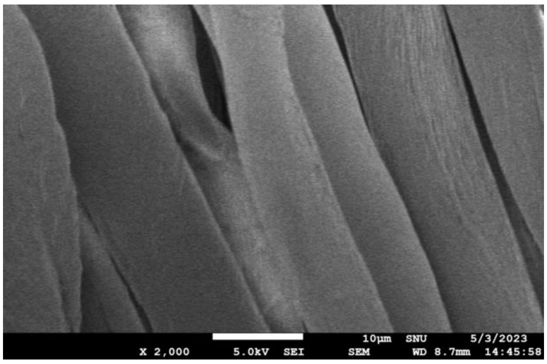


Figure 2 SEM image of untreated cotton fabric

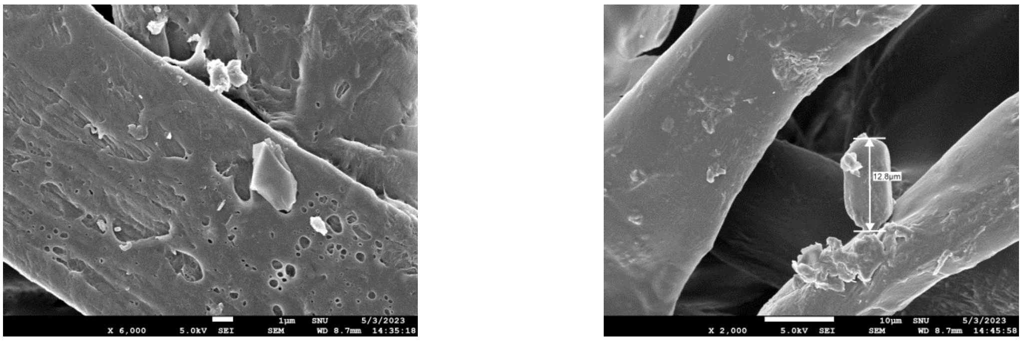


Figure 3 SEM images of treated cotton fabric along with size distribution of microcapsules

3.3 FTIR analysis

The FTIR spectra of the Lantana camara essential oil, untreated cotton fabric and treated cotton fabric are presented in Figure 4. FTIR analysis was performed to ensure the presence of the Lantana camara essential oil on the treated cotton fabric. The FTIR results of all the three mentioned samples were compared.

It was observed that functional groups present in the cotton at 3483.8 cm^{-1} corresponds to the -OH functional group which was present in both the treated and untreated cotton fabrics. The peaks at 2927.3 cm^{-1} and 2923.5 cm^{-1} in treated fabric and lantana camara essential oil spectra respectively which are related to C-H stretching vibrations. The Lantana camara essential oil spectrum displayed a ketone group at 1741.4 cm^{-1} which was also present in the treated cotton fabric with microcapsules of Lantana camara essential oil. Overall, FTIR analysis represents the present of major components present in Lantana camara essential oil including, alkaloids, flavonoids and terpenoids.

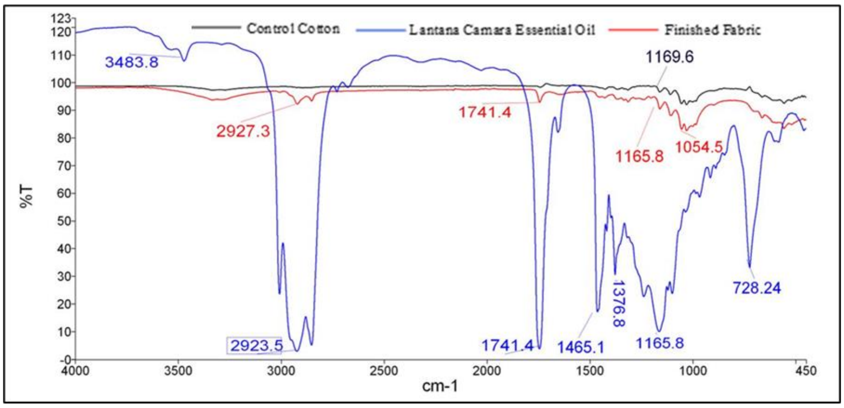


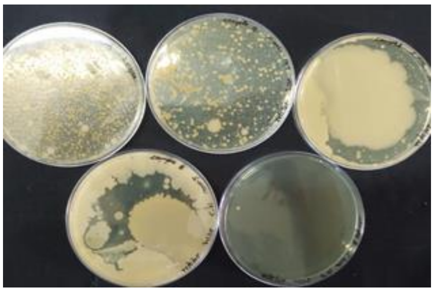
Figure 4 FTIR of Lantana camara essential oil, untreated fabric and treated fabric with microcapsules of Lantana camara essential oil

3.4 Assessment of antibacterial properties of the finished fabric

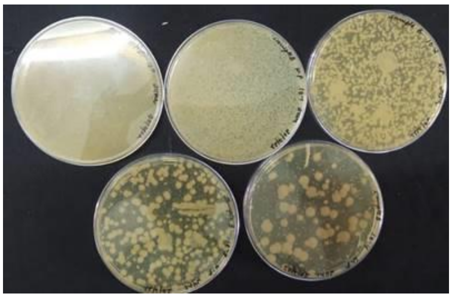
.The antibacterial activity of untreated and treated cotton fabric finished with microcapsules of Lantana camara essential oil are displayed in Figure 5 and 6. The treated cotton fabrics showed excellent antibacterial percentage with 99% and 94.3% against gram-positive (Staphylococcus aureus) and gram-negative (Klebsiella pneumoniae) bacteria respectively.

Some of the active chemical components i.e. lantadenes and theveside might be responsible for the antibacterial properties of Lantana camara essential oil. The antibacterial effects of Lantana camara may also be due to the presence of phenolics, anthocyanins, and proanthocyanidins. Lantadenes is accountable for nearly all the biological activities.

Additionally, various other secondary metabolites, including flavonoids, terpenoids, phenolics, sesquiterpenes, tannins and alkaloids are powerful antibacterial agents that can effectively combat a variety of microbes (Naz and Bano 2013).



Staphylococcus aureus



Klebsiella pneumoniae

Figure 5 Antibacterial activity of untreated fabric

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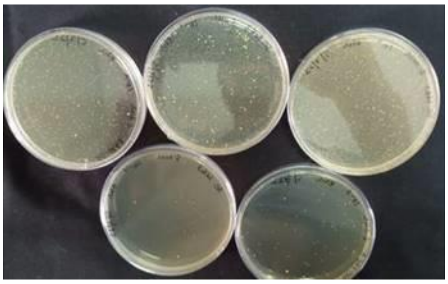
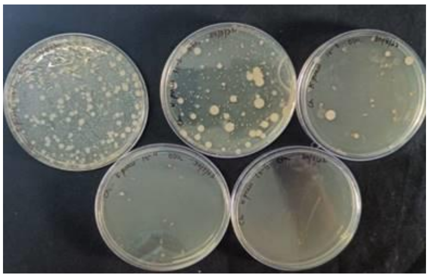


Staphylococcus aureus



Klebsiella pneumoniae

Figure 6 Antibacterial activity of treated fabric
(Five petri dishes in each image represents serial dilutions (10^{-1} to 10^{-5}))

3.5 Assessment of antibacterial properties of the finished fabric after laundering

The cotton fabrics treated with microcapsules of Lantana camara essential oil displayed good antibacterial properties after washing, with 96.8% and 90% against Staphylococcus aureus germs and Klebsiella pneumoniae, respectively as represented in the chart in Figure 7 which signifies the attachment of the microcapsules to the fabric even after washing.

The adhesion of the microcapsules to the cotton fabric might me due to effective encapsulation of Lantana camara essential oil in Gelatine- Gum Arabic complex, providing slow release of the essential oil due to suppressed volatility of the oil. Also, it can be attributed to the cross-linking process with glutaraldehyde which is responsible for developing film around the wall-core structure, providing an appreciable controlled-release property.

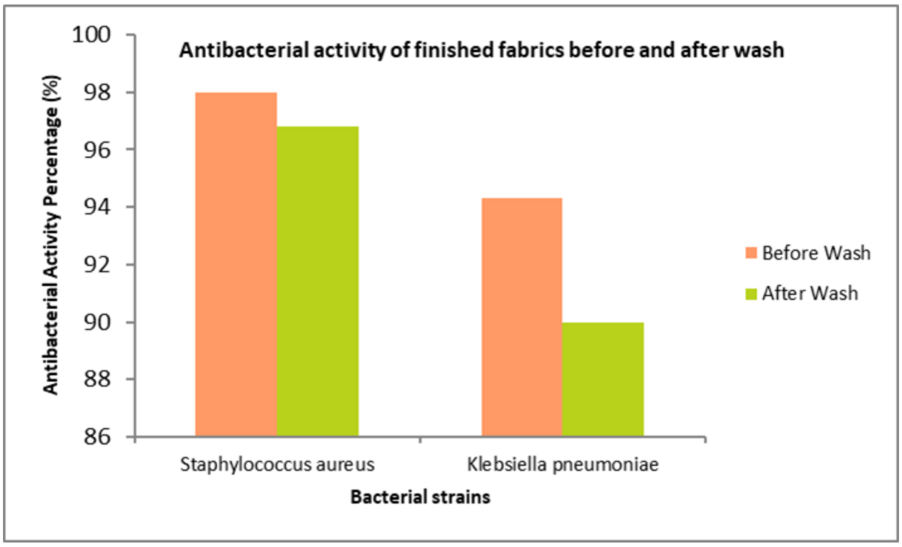


Figure 7 Antibacterial activity of treated fabric after laundering

4 Conclusions and recommendations

Recently, post Covid-19, there has been a growing interest towards the development of antimicrobial textiles as a result of increased public awareness of personal protection, disease transmission and sanitation. The textile industry is also continually aiming to develop and improve products by utilising advanced techniques, innovative materials, and functional finishes. But when creating these textile products, environmental factors are also considered in combination with the new developments.

The results of the present study revealed that Lantana camara is a powerful antimicrobial agent with every part of the plant being used for different biological activities and medicinal purposes. Microencapsulation using complex coacervation technique with Gelatine and Gum Arabic as wall materials loaded with essential oil of Lantana camara has resulted into a strong and stable complex. The developed fabric exhibited excellent antimicrobial properties with 99% and 94.3% against gram-positive (Staphylococcus aureus) and gram-negative (Klebsiella pneumoniae) bacteria respectively. Even after laundering the antibacterial percentage was found to be 96.8% and 90% against Staphylococcus aureus germs and Klebsiella pneumoniae, respectively which is also possible with the use of glutaraldehyde and if the concentration of cross-linker is increased, it might result into good was durability.

Thus, future research must be directed toward exploring the potential for other properties which can be imparted by using essential oil of Lantana camara and its extracts. The wash durability factor and storage time could also be considered. Lantana camara is an evergreen plant which can be found throughout India and its chemical constituents make it a great potential for multifunctional properties in textiles.

Roles of author

N.S. and M.S.P. supervised the study and R.K. designed and performed the experiments and the results were compiled by all the authors.

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Conflict of interest

The author declares that there is/are no conflict of interest.

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Improving the efficiency of fabric filters to capture the COVID virus

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Abstract

Passive filter mechanisms rely on the physical entanglement of particulates. Therefore, to be of sufficiently low porosity to prevent the further passage of the particulates through the filter particulates must come into direct contact with a mesh of fibres smaller than the target particles. Increasing capture efficiency by decreasing porosity increases flow resistance. This is problematic for face coverings, where high flow resistance encourages the passage of breath around the face-covering rather than through it. In the social setting, wearing a face covering is a voluntary activity. So, to achieve a high level of compliance, user comfort is important.

In this case we consider improvements over passive filtration if a virus can be bonded to the filter using molecular biology and chemical mimicry to entrap the virus. Biochemical fibre admixtures enhance the propensity for viral binding through developing a molecular-level synergy on the polymer substrate which exploits the COVID-19 spike to hACE2 receptor interaction. We identify two possible adhesion enhancers: fucoidan and β-glucan.

Filter performance was assessed using BS ISO 18184:2019 'Textiles — Determination of antiviral activity of textile products for antiviral properties', achieving results better than 99% for fucoidan (the control filter materials retained 55%) and better than 97% for β-glucan (the control filter materials retained 32%): these values indicate the proportion of the human coronavirus 229E ATCC VR-740 virus that was immobilised by the treatment. We also present a commercially viable face cover design that uses the biomimetic techniques described in a sustainable origin biodegradable filter element.

Keywords: Barley β-glucan, Fucoidan, Covid-19, Active Filtration, Face-covering

1 Introduction and aims

The University of Lincoln, United Kingdom (UK) formed a partnership with the New Zealand Institute of Plant and Food Research to help in the struggle against the Covid pandemic. A combination of work on the practical design of a face covering (Figure 1), pharmaceutics and biochemistry, and manufacturing engineering was required to produce a practical and effective Covid specific face covering. A face covering differs from personal protective equipment (PPE) in that the use of a face covering is a voluntary activity whereas the use of PPE is obligatory being mandated by legislation. So, for a face covering to be successful, it must a high degree of voluntary take-up: so, it must be comfortable and stylish. For the wearer, the ideal face covering should not be claustrophobic. This is achieved by using a material with high air permeability to allow freer passage of breath through the covering rather than around it. From the view of simple engineering performance this is contradiction: passive filter mechanisms rely on the physical entanglement of particulates. Therefore, aerosols must directly contact the mesh of fibres, which must be of sufficiently low porosity to prevent the further passage of the aerosols through the filter. Improvements to the rate of capture by this method will decrease porosity and increase resistance to flow. Improvements of this type are likely to be of little benefit, if the face covering becomes uncomfortable, and therefore undesirable to wear. It was proposed to address this difficult by moving to an active filtration system whereby the aerosol pathogens are chemically bonded to the filtration material. Thus, simple contact with the filter fibres is enough, and a more permeable material can be as effective as a lower permeability filter.

Figure 1 The face covering design using a disposable biodegradable active filter element (Picture: School of Design, University of Lincoln)

Based on work by Kwon et al (2020) the authors first selected fucoidan, a sulfated water-soluble polysaccharide extracted from brown seaweeds such as *Ascopbyllum nodosum*, *Fucus vesiculosus*, and *Saccharina japonica*, and commonly used as a nutraceutical for the first trials. Kwon et al (2020) demonstrated that it causes Covid viruses to stick and become immobilised on surfaces. In addition, a β-glucan barley extract which has a number of applications varying from anti-staling in baked goods, as an emulsifier, as an emollient cream, and has intrinsic anti-bacterial functionality was identified as a biochemically likely material.

These materials have the potential for an improved filter using molecular biology and chemical mimicry to attract and entrap the virus on the fabric, enhancing capture efficiency over conventional passive filter materials. Furthermore, the biochemical fibre admixtures enhance the propensity for viral binding through developing a molecular-level synergy on the polymer substrate which exploits the COVID-19 spike to hACE2 receptor interaction.

The efficacy of the two possible adhesion enhancers: fucoidan, and β-glucan were assessed using BS ISO 18184:2019 'Textiles — Determination of antiviral activity of textile products for antiviral properties', achieving results (Table 1) better than 99% for fucoidan, (the control filter materials retained 55%) and better than 97% for β-glucan (the control filter materials retained 32%): these values indicate the proportion of the human coronavirus 229E ATCC VR-740 virus that was immobilised by the treatment.

2 Materials and Methods

Fucoidan was sourced from Anhui Minmetals Development I/E Co., Ltd, via Hefei Joye Import & Export Co., Ltd Baishengyuan Shushan District, Hefei Anhui, China. The test solution was 5wt% in de-ionised water.

The β-glucan used is extracted by a proprietary process from barley grain. The material was supplied by the New Zealand Institute for Plant and Food Research Ltd pre-impregnated into wool felt and was used as supplied.

Promoting adhesion of the virus to the fibre and rendering it harmless requires physical and chemisorption of the virus to the fibre. A route to this was envisaged exploiting the binding mechanism the target virus specifically exploits. For SARS, the method in which the SARS-CoV-2 spike interacts with the target receptor in humans, is hACE2. These structures are available in the Protein Data Bank (PDB). For example, an atypical structure which exemplifies the spike protein on the virus and receptor configuration is PDB reference code 6LZG, (Wang et al 2020). The binding pocket in the hACE2 receptor has strong polar interactions with hydrophilic residues along the virus interface creating a ‘solid network of hydrogen-bonding and salt bridge interactions’ (Wang et al 2020). Further, the SARS-CoV-2 virus binds to the receptor using a spike protein (S-protein) (Zhu et al 2020); the residues that are critical for this are Gln493 (glutamine) and Asn501 (asparagine) (wan et al 2020). In addition, they bind to two lysine hotspots in the hACE2 receptor, Lys31 (hotspot 31) and Lys353 (hotspot 353) respectively (Shang et al 2020). The lysine (Lys) residue relationship using 6LZG, within the receptor is shown in Figure 2, with the transition across from S-protein on SARS-CoV-2 to ACE2 receptor (A) and the specific peptide arrangement exploited (B).

The S-protein of SARS-CoV-2 is extensively shielded by glycosylation with the exception of the hACE2 receptor binding domain (Grant et al 2020 and Watanabe et al 2020). This section of the S-protein is the only exposed section that is available to interact with the receptor as glycosylation of the protein is ‘disproportionately high at 42%’ (Grant et al 2020).

The S-protein actively seeks glycans, particularly N-linked glycans, such as mannonanose-di-(N-acetyl-D-glucosamine), for shielding (Grant et al 2020) Mannonanose-di-(N-acetyl-D-glucosamine) provides 47% of the S protein coverage (Grant et al 2020).

The PDB 6LZG X-ray structure of the SARS-CoV-2 spike interacting with the receptor (Figure 3) shows the key lysine interaction that occurs between the S-protein and receptor. The glycans surrounding the S-protein do not prevent hydrogen bonding occurring (Shang et al 2020).

This demonstrates, the physiochemical utility of linking the molecular biology to the chemical motifs to be employed as follows. To attach the virus to the fabric requires chemisorption. This can be achieved by mimicking the hACE2 receptor binding site, using lysine residues and hydrogen bonding. The inclusion of a glycan such as N-acetyl-D-glucosamine, a subunit of mannonanose-di-(N-acetyl-D-glucosamine), offers another non-specific binding opportunity between the S-protein and the fibre. These targets synergise with the structural picture and envisaged route to capture the chemical essence of a mimic of the target receptor detail of the SARS-CoV-2 spike. Thus, we demonstrate the potential to fabricate a filter by deposition of a solution capable of immobilising the virus on a ‘ghost’ receptor.

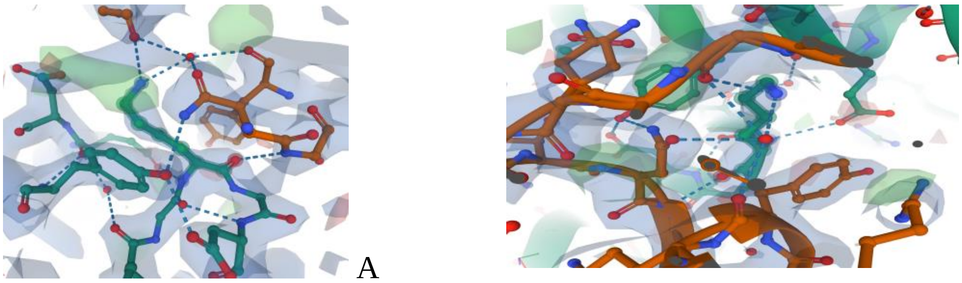

Figure 2 A) The overlay between SARS-CoV-2 and the ACE2 receptor, B) Specific binding of the hACE2 lysine with SARS-CoV-2 S-protein, particularly the recognition surface lysine. Projection taken by applicants using the 6ZLG structure in PDB database.

Both Fucoidans and β-glucans are glycans but are different in structural configuration and the monomers constituting the polymer chains. β-glucan is a macromolecular polysaccharide with glucose monomers as the building unit. A number of studies have demonstrated that β-glucans possess intrinsic anti-microbial, anti-inflammatory, and immune-modulation efficacy (Micháľová et al 2019). β-glucans have anti-infective and anti-bacterial activity against a broad spectrum of Gram-negative and Gram-positive bacteria (Chamidah et al 2017). In terms of immunostimulatory activity, β-glucan binds to receptors found on the surface of macrophages, neutrophils, monocytes, and natural killer cells (Singer and Clark 1999). It is suggested that activated macrophages initiate a sequence of reactions involving cytokines and growth hormones and other immune related molecules. Almost all reported data describe the efficacy of yeast and fungal β-glucans not cereal β-glucans. Razzaq et al (2021) reported anti Gram-negative and Gram-positive functionality of protein- β-glucans based films made from β-glucans and proteins that were simultaneously extracted from barley grains.

As mentioned earlier, the S-protein of SARS-CoV-2 binds to domains on the membrane of the host cell that contain certain amino acids residues. Glutamate (glutamic acid) residue seems to play a significant role in the process of S-protein binding (Socher et al 2021). Glutamic acid and proline are the two dominant amino acids in barley proteins. Thus, the ability of β-glucans to bind to biologically active molecules together with the presence of the glutamate in the barley proteins may present the extract as a candidate for the capture of the SARS-CoV-2 virus.

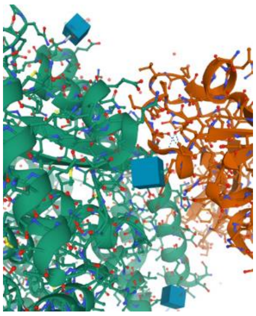

Figure 3. A visualization of the interaction between the hACE2 receptor domain (green ribbon) with a glycan sugar (blue box) and the spike protein of COVID-19 (brown ribbon) at lysine site LYS353. Projection using the 6LZG structure in PDB database.

The test substances were impregnated into 2mm thick wool felt (13W grade supplied by Messrs. Anglo Technical Textiles, Tong Lane, Whitworth, Lancashire OL12 8BG) with a 5wt% aqueous solution of the various test materials. The samples were then dried at room temperature and humidity and tested by MSL Solution Providers, Lancashire - an independent test laboratory to BS ISO 18184:2019 The method involves placing and incubating a small amount of Human coronavirus 229E ATCC VR-740 on the treated and untreated fabric for a specific contact time, according to ISO 18184 procedures. At the end of the test, the amount of virus surviving on the treated and untreated control fabric is counted and the reduction rate is calculated. This is expressed as a percentage reduction on the test report (Table 1). The results presented are an average of three tests.

Table 1 Percentage of Human coronavirus 229E ATCC VR-740 immobilised as measured by BS ISO 18184:2019

Material	Supplier	Control fabric Retention	Treated fabric Retention
β-glucan	NZ Institute for Plant and Food Research, Lincoln, New Zealand	31.87%	97.39%
Fucoidan (5%wt aqueous solution)	Anhui Minmetals Development I/E Co., Ltd, via Hefei Joye Import & Export Co.,Ltd, Baishengyuan Shushan District, Hefei Anhui, China	55.05%	99.62%

3 Results and discussion

The test work indicates improvements in virus filter efficiency without a concurrent decrease in permeability. This finding can be applied in the production of disposable face covering filter elements, or as a topical treatment for existing fabric face coverings. The barley β-glucan extract is the preferred active ingredient in the filter element as it does not smell and is likely to be cheaper than the fucoidan.

4 Conclusion

A combination of pharmaceutics and biochemistry, and manufacturing engineering was required to demonstrate an active filtration system whereby specific aerosol pathogens are captured by being chemically bonded to the filtration material. The addition of any of the test substances to a fabric substrate significantly increases the efficiency of the filter without detectable increase in resistance to flow through the filter element. A material with high air permeability allows freer passage of breath through the covering rather than around it, so a more permeable material can be as effective as a lower permeability passive filter. This is important for the design of face coverings for wide-spread voluntary use.

Roles of authors

Supply and preparation of the β-glucan samples (H.R); Study Conception and Design (N.B, E.W); Experimentation – Collection of data (N.T); Analysis and Interpretation of Results (E.W, N.B); Writing the Original Draft (N.T, N.B, E.W, H.R); Writing-review and Editing (H.R, N.T); Over-all supervision (N.T, E.W, N.B).

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Conflict of interest

The authors declare that there are no conflicts of interest.

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Design and development of personalised face mask with highly efficient functionalised and replaceable filter media

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Abstract

Air pollution caused by proliferation of dust, various harmful gasses and particulate matters, air-borne viruses and microorganisms have become major causes of global health hazard causing various respiratory illnesses and increased sources of morbidity and mortality to human life. Currently available single and multiple-use disposable face masks, particularly post COVID-19 pandemic, are suspect to serious environmental concern, when disposed of in huge quantity. The sub-optimal use of filter media in such masks for effective filtration of respiratory air, results in unnecessary production, consumption and wastage. Issues like leakage and discomfort due to faulty fit of these generically designed masks on the users' faces further reduces the effectiveness of such presently available products.

The present research aims to efficiently tackle such challenges by effective design and technological intervention. Such design innovations are aimed to achieve maximum utilization of the filter media and creating semi durable structure which can be safely and effectively used

repeatedly over an optimum span of time. The present work demonstrates a novel design idea of face mask, which have the active filtering media being replaceable, keeping the holding part of the mask reusable and recyclable.

The present design solution would enable production of customized mask as per users' face contour using advanced design and manufacturing technologies like 3D scanning, 3D printing, melt spinning etc. These not only ensures leak proof comfortable wearing experience and effective use of filter media but at the same time makes the process of designing and manufacturing of masks more ecologically and financially sustainable.

Keywords: Air Pollution, Filtration, Design Innovation, Sustainability, Personalisation, Textile Fabrication, 3D Printing

1 Introduction

Air pollution, a seemingly perennial worldwide problem that affects people of all ages from kids to the elderly. With its wide-ranging effects (Figure 1) from obstructing respiratory tract to causing allergy and asthma, to lung disease and to the long term neurological disorder, air pollution has become a serious contributor to The Global Burden of Disease. Surprisingly, India has 3 cities in the list of 10 most polluted cities in the world. Besides dealing with these problems, certain emergent situations arise where people need to be protected from dangerous gaseous and chemical pollutants. Recent incidents of the Visakhapatnam gas leak is a burning example of this type of emergent situation where cleaning up gaseous pollutant from contaminated air stream remained prime focus to provide breathable clean air to the people of that locality for their survival. Covid-19 pandemic had just added more problems to the already existed air pollution problem in our life. A study by the Indian Council for Medical Research (ICMR) found that air pollution killed 16.7 lakh Indians and also wiped out ₹2.6 lakh crore from the economy in 2019. Also, it's not only the outdoor air pollution that is posing a serious threats to our life, but the indoor air pollution is also making in-roads slowly but surely into our lives and making it difficult for us to live healthy life inside our house. It has also been reported that a person living for decades in a county with high levels of fine particulate matter is 15 per cent more likely to die from the coronavirus than someone living in a region with one unit less of the fine particulate pollution .Thus, the outdoor and indoor air pollution are not only leading to increased respiratory diseases but also offering an important source of morbidity and mortality to human life .

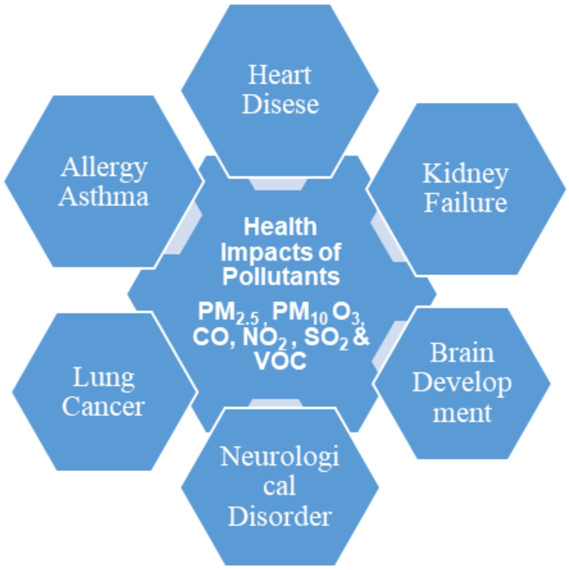


Figure 1 Established outcomes of short-term and long-term exposure to air pollutants (gaseous and particulate)

Sub-optimal usage of filter media

There are currently numerous companies that are actively involved in manufacturing of masks, manufacturing nearly about 15 million pieces of masks daily. During the pandemic situation India's daily requirement of masks was approximately 65 million (as per very conservative calculation). Most of those masks are disposable after single use (as was advisable). Such a situation caused a demand supply gap initially and created scopes for innovation and new entrepreneurships. Even in this post pandemic world personal and professional health care sector requires systemic use of face masks and thus the consumption is in multi-million figures.

The currently available layered masks, such as triple layer medical mask or N-95 respirator masks are all disposable. After single-use, these masks are being thrown away to dust bins and then to landfills. Huge amount of raw materials could be saved if some parts of these masks are being reused. These triple layer masks, comparatively cheaper, are not free from flaws; one of them being their lower filtration efficiency in containment of certain types of air pollutants. Whereas, the N-95 respirator masks provide better protection through its highly efficient filter media sandwiched in between its layers, but come at a much higher cost than that of these triple layer masks in the market.

The number of COPD cases in India was a staggering 55.3 million in 2016 and is the second common cause of deaths due to non-communicable disease (NCD) and air pollution increases the risk of it in healthy people. Evidence from India suggested the COPD prevalence increases with age and exponentially after 30 years of age. The estimated prevalence of COPD ranged from 0.1% to 0.9% between the age group of 5 years to 29 years while the incidence ranged from 1.6% to 28.3% in population above 30 years of age.

The above situations throws light on the magnitude of mask consumption which has become inevitable. Such large quantity of masks which are mostly made out of synthetic polymers like polypropylene, or some other mostly non-biodegradable polymers create long term hazard for ecology. Polypropylene may take 20-30 years to degrade. Even if some biodegradable polymers are being used, the magnitude of waste generated by frequent disposal of such large quantity of masks are posing serious threats to global environment and ever-increasing burdens of landfills.

Another issue that came to lime light during pandemic was the fit of the mask on the faces of wearer. Till date the mass manufacturing of masks happens based on scientifically analysed design templates and such templates come with their individual pros and cons. But all these happens on the basis of a generic design with limited or no scope of customisation. This leaves a lot of instances of misfit, loose fit or sliding down cases. These not only make the wearing uncomfortable but has potential to create gaps to allow inflow/outflow of contaminated air, in turn. Most of the time such kind of masks are entirely made up of the filter media, except for industrial gas masks. This also causes suboptimal use of the filter fabric / media.

Moreover such masks are manufactured mostly using multiple stiches or joints of different types which makes the manufacturing process time and technology intensive. Quality and fit related issues crop up more often than not because of such multiple joints or stiches, even if the quality of filter media is satisfactory.

Therefore the present state of the art of face mask design, manufacturing and usage opens up further scopes to research, innovation and improvisation as has been attempted in this work. Through this work a design innovation approach is being researched where the following concerns shall be addressed:-

a) Creation of a multi zonal design where the effective filtration zone and the holding zone on the face are detachable. This would enable disposal of the filtration zone after recommended lifecycle and replacement with fresh filter media. But the holding zone can be reused for prolonged period of time.

b) Designing a system of customisation of the shape of the holding zone as per facial contour of individual wearer using existing 3D scanning and image processing technologies.

c) Manufacturing of the masks in seamless modular form employing latest 3D printing technology eliminating multiple manufacturing steps.

2 Materials and methods

To 3D print the face mask, different synthetic materials were used such as TPU (Thermoplastic Polyurethane). To prepare the replaceable composite filter media, nonwoven needle-punched and melt-blown fibrous mat were used.

A slew of equipment was used to 3D print the face mask. A hand-held 3D scanner (Structure Sensor (ST 01) made by Occipital Inc., USA) was used to scan the face of the subject. The scanner was attached to a tablet with 4 GB RAM and 64 GB storage space to real-time visualisation of the scanned image in 3D format through an app called as Structure SDK that would help save the image in the internal storage space of the tablet.

The 3D scanned image was then imported and processed through specialised software named as Skanect Pro provided by the Occipital Inc. After the processing of the 3D scanned image, the file was exported to another 3D editing software named as Rhinoceros 3D (version 7) design software. The detailed method of the process from scanning to printing of the face mask is described in several steps in the below section.

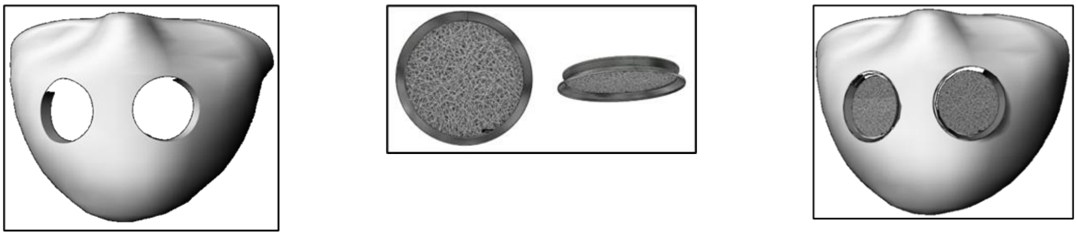
Step 1: To get the customised face mask, the face scanning was done first. The subject was volunteered by one student and her face was scanned using the hand-held scanner (Structure Sensor) and Structure SDK app installed in the tablet to get accurate face contour of the subject.

Step 2: The scanned file was then exported to software called Skanect Pro for editing and bettering its image quality. The pictures of the editing process (Prepare-Record-Reconstruct-Process-Share) have been shown in the following section.

Step 3: The edited version of the Skanect Pro file was then exported to a visual editing software Rhinoceros 3D (version 7) and the mask was designed using the peripheral face contour of the subject, required for the effective coverage of the face of the subject which is desirable for leak-proof mask.

Step 4: Once the editing was done, the file was saved in (.STL) format for its being ready for the 3D printing. The file was then exported to 3D printer's editing software (Ultimaker Care) to finally edit the 3D printable file to get its dimensions (thickness, length, width and height) right.

Figure 2 Cropped face scan for getting the face contour of the subject



(a) (b) (c)

Figure 3 (a) Digital 3D image without filter in created Rhino, (b) Detachable Filter created in Rhino, (c) Digital 3D image with filter created in Rhino

Figure 4 Actual 3D printed face mask in different views

Conclusion and recommendations

Through this prototype development the concerns related to design, manufacturing and usage of face masks have been addressed.

The mask was designed in two distinct parts. The holding part, which was 3D printed during this work, was made of TPU (Thermoplastic polyurethane) which is flexible, nontoxic and can be used for prolonged period of time. The disposable filter inserts can be easily but smugly fitted into the circular void spaces of the holding part, as depicted in the figures. This would enable disposal of the filtration insert after recommended lifecycle but the holding zone can be reused for prolonged period of time. Thus the concern of frequent disposal of the entire mask has been addressed along with optimisation of the use of costlier filter media, by limiting its use for making the filter inserts only. It is expected that such design endeavour shall mitigate the environmental concern arising out of disposal of large quantity of used masks.

The process of customisation to determine the contour design of the face mask based on individual subject's face pattern, opens up the opportunity to achieve second skin like fitting of the mask on the face of the user. This would intern help minimise leakage of contaminated air while inhalation and exhalation.

The manufacturing of the masks by 3D printing process followed in this work points towards possibility of modular, single stage and seamless manufacturing process. This helps address the concerns of complexity of existing manufacturing process in terms of preparation of the filter fabric, cutting, stitching etc. The concern of quality deviations arising at those different stages of conventional manufacturing is also mitigated by this single stage conversion process of 3D printing from design to product.

Optimisation and standardisation of the scanning and image generation process could be the scope of further research. Development of an objective evaluation process to fine tune the fitting of the mask as per the user face contour can be worked upon.

Roles of author

Ideation and Concept Development (M.B.), 3D Scanning & Digital Design (M.B, S.B.), Product Experimentation & Fabrication (S.B, M.B, S.M.), Original Draft Writing – (M.B.), Review of Draft – (S.B., S.M.), Overall Supervision (S.B, M.B., S.M.).

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Conflict of interest

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