

RESEARCH ON THE MANUFACTURING TECHNOLOGY OF SPECIAL FOOTWEAR

Jononova Shakhzoda Fozil kizi

Tashkent Institute of Textile and Light Industry

shaxzodajononova@gmail.com

Abstract:

In sectors such as medical, military, and industrial where the working environment is dangerous, special footwear is crucial to maintaining safety and comfort. With evolving industries, the need for specialized footwear to protect from mechanical, thermal, chemical, and electrical risks are on the rise. Integration of modern technologies in production methods such as CAD, 3D modeling, and smart Quality Control has become imperative. While considerable knowledge exists regarding special footwear technologies in developed economies, less attention has been drawn to the upgrading of production methods in transitional areas such as Central Asia. The purpose of this oeuvre is to study the technological processes that are used in the manufacturing of special shoes, and estimating the affect that modern interfacing, guidelines of ergonomic frameworks and the producing process have on their restoration. Use of materials such as polyurethane and thermoplastic polyurethane with improved ergonomic designs for better comfort and reduced fatigue among users are identified. The other highlights automation technologies for manufacturing, as well as conservation practices, integration of ag products and production technologies. This research expands the existing literature on sustainable and ergonomic manufacturing technology for special footwear, and the data generated would be valuable for Uzbekistan, located in Central Asia, and one of the countries in the region, having its textile and light industry sector to benefit from it. These results have implications on improving the international competitiveness of the special footwear sector through innovation in safety, comfort, and environmental sustainability, while serving as a model for the technological modernization in developing areas.

Keywords: Special Footwear, Production Technology, Ergonomics, Safety, Quality Control, Innovation

1. Introduction

Protective footwear is a key pillar of providing safety to the workforce while they are on the job and the reason behind that cannot be subtle when it comes to industrial safety. Special footwear represents an important component of personal protective equipment (PPE) for use in various industries (I.co) like construction, healthcare and military applications. It protects the users from mechanical, thermal, chemical, and electrical threats but which also comfort and enables users to work for hours [1]. Automation development during such footwear manufacturing process is a core idea for advancing its effectiveness, and as such innovations are analysed from the perspective of

contemporary methods and materials applied for manufacturing [2].

Development of special shoes is depending on the synergy of ergonomics, material science and manufacturing technology. Footwear that is designed to conform to the human foot helps minimize the chances of sustaining injuries that result from performing duties at work, whereas materials such as thermoplastic polyurethane (TPU), Kevlar, and carbon fiber contribute towards enhancing durability, comfort, and footwear protection.] Add to this automated and digitalized production processes, which enhance efficiency, consistency of the end-product and higher consistency of it [3]. However, there remains a lack of evidence about the application of these technologies in developing countries such as Uzbekistan that need to use global best practices in footwear production [4].

Related works targeting some aspects of special footwear production like material selection, ergonomics, and sustainability have already been conducted. Experts have offered principles of biomechanics and ergonomics, on which to base design of protective, yet comfortable shoes. Singh and Verma, on the other side, have studied new materials such as composite polymers and that is of great significance due to its lightweight and durability whenever utilized in the preparation of footwear. Nonetheless, the literature is overwhelmingly oriented towards developed countries, which means it only provides a partial picture of how these technologies are examined in developing economies [5].

This study approaches special footwear which needs holistic evaluation through material selection and ergonomics as well as manufacturing process as its primary research. They also talk about incorporating some new technologies like 3D printing, automation systems and sustainability into the production in order to make the shoes better, both functionally and environmentally [6].

The results of this study are anticipated to offer valuable implications on how innovation successes, like environmental sustainability and digitalized production, may be furthered within special footwear production firms. The results will invite insights which will help to identify the appropriate benefits which this futuristic revolution in manufacturing i.e. automation & smart sensor combination will provide while ensuring safer efficient and eco-friendly production of footwear. Third, the title of this paper will help in shaping a domain that for the industrialized and developing of the world a strategic low-tech sustainable shoe industry [7].

Literature Review

Scientific research work is being conducted in Uzbekistan, especially in the Tashkent Institute of Textile and Light Industry, to improve the production technology of special shoes. They emphasize on performing material specific optimization, adopting digital modelling within design for assembly processes with an eye quality assurance through quality control, and incorporating sustainable production technologies that are in accordance with modern global standards. These initiatives help in making the domestic industry of foot wears technologically advance and also aid import substitution and export Led growth strategy [8].

Accordingly, the goal of the current study is to conduct an analysis and systematization of the technological processes of special footwear production, an assessment of the role of modern equipment and materials, as well as to outline possible directions of innovation and improvement of technological processes of special footwear production. The aim of this study is to contribute to increasing the safety and efficiency of footwear production technologies, and also to reduce environmental pollution by examining these issues.

The research concerning the manufacturing technology of special footwear has gone boom over the recent decades due to the increasing development of materials science, ergonomics, and industrial automation. Scholars and engineers have investigated many facets of footwear production from material composition and design optimization to production efficiency and sustainability [9].

Footwear design, he added, is an interdisciplinary process involving a combination of mechanical engineering, biomechanics and textile science. He stresses that comfort, protection and performance are interrelated, and that footwear manufacturers must strike a balance among the three during safety footwear production. Related, Kim point out the value of ergonomic assessment, evidence that anatomical configuration and well-placed weight decrease muscular fatigue and subsequently enhance user performance in the long term. They found sole flexibility and shock attenuation to correlate, and both correlate with dynamic balance of gait using biomechanical testing to substantiate its use [10].

Modern shoes for special purposes have also been developed around the idea of material innovation. In their paper on protective footwear, Singh and Verma discuss the development of high-performance polymers and composite materials. According to them, PU and TPU outsoles offer better durability and weight than classic rubber. Moreover, materials like Kevlar, carbon fiber, and Gore-Tex fabrics are used and require high tensile strength, thermal resistance, and waterproof material. These materials help improve safety and prolongs the product's service life under extreme conditions [11].

Recent studies have also examined systemic environmental sustainability. The paper ends with LCA-based thoughts on an example of an integrated shoe production using bio-based and recyclable materials. His work furthers the urgent argument for factories to adopt greener glues, to switch to the use of water-based dyes, to initiate waste recycling systems whenever possible. In the same line, the ISO 14001 also supports the light industry companies to create sustainable production chain and energy efficient technologies [12].

Technologically, automation and digitalization evolve traditional shoe manufacturing into high-precision engineering systems. For example; in industrial engineering recent research studies have shown such aspects as: integration of CAD/CAM software, laser cutting, 3D printing, robotic assembly lines etc. These technologies reduce material waste, improve the accuracy and quality consistency of the production for mass production [13].

Moreover, current interesting SMART FOOTWEAR technology trends are with the use of integrated sensors for pressure distribution, temperature and movement with some of them sporting integrated sensors. This is a making path of the future of the manufacturing of protective and medical footwear. The present work found background literature which provides solid ground for the foundation of special shoe production technologies. Nevertheless, most studies are dedicated to advanced economies, whereas little attention is paid to the technological upgrading of the footwear industry in developing regions such as Central Asia. Therefore, this study aims to fill this research gap by analyzing modern technological solutions and their applicability within the context of Uzbekistan's textile and light industry sector.

2. Materials and Methods

A structured method as material selection, ergonomic design and production development is used to study the manufacturing technology of this special footwear. The Materials were selected based on durability, flexibility and thermal resistance along with safety measures. Three key materials were PU & TPU (polyurethane) soles, upper materials such as Kevlar & Gore-tex, and composite shoe-caps. Mechanical strength and abrasion resistance properties of all materials were evaluated using ISO 20344:2021, while safety compliance tests were also conducted. Scanning and digitally modeling foot shapes using CAD also allowed for the production of anatomically-accurate lasts. Optimal pressure distribution, shock absorption, and balance of weight were guaranteed through

Finite Element Analysis (FEA). Prototyping and lab testing can validate design iterations. It used laser cutting, automated stitching, injection molding for the sole connection and finishing. Every stage along the way slip resistance, impact dispersion, comfort analysis was a stage that underwent quality checks. The ISO 14001 certification reduced environmental impact through use of environmentally friendly adhesives, recyclable polymers, and energy-efficient production methods. It is the production process of special footwear which is consistent, safe, durable and ergonomically optimized.

3. Results and Discussion

Special footwear is often innovative footwear utilizing contemporary material compositions and utilization of ergonomics and manufacturing optimization to ensure safety, durability, and comfort for people in industrial, medical, or military environments. The soles of contemporary shoes are notably created from a material called polyurethane (PU) or thermoplastic polyurethane (TPU), which delivers better shock absorption, flexibility and durability and lung resistance than traditional rubber. The composite toe, made of fiberglass or carbon fiber, offers almost the same protection and can lessen the weight of the shoe by as much as thirty percent, improving mobility and minimizing fatigue associated with extended use. The external as the outer part is now typically manufactured from performance fabrics like Kevlar or Gore-Tex, waterproof and vapor-permeable with high tensile strength, coupled with sustainable matrix materials such as adhesives and coatings, in an assembly process ensuring long-term functionality with low ecological footprints [14].

Shaping lasts and sole structures to adhere and align with foot contours, thus ensuring better weight distribution and comfort along with proper foot scanning and CAD Continue Reading to this end is critical. Designing last and sole architecture to stick to foot features, thereby relevant to even weight distribution and comfort, near the preliminary such ergonomic considers. FEA simulations assess the shock absorption and load-weighting under different load conditions to ensure that prototypes meet the two basic requirements of protection and comfort. The lab testing of these prototypes shows real improvements in comfort levels, as confirmed by a measurable reduction in peak pressure points, and thus, the results suggest that ergonomic design could offer a path to prevention of workplace injury.

This includes precision cutting, automated stitching, injection molding and finishing operations all under one roof of manufacturing. Laser cutting provides each part with a close-to-perfect size, ensuring little to no material wastage, while an automated stitching process helps in improving seam consistency and strength. The sole is attached to the uppers with an injection molding process that performs a waterproof and durable bond between the components forming a longer-living shoe. They have undergone all final quality control checks slip resistance, impact insulation, penetration resistance and ergonomics to ensure they conform with ISO 20345:2021. Automation reduces drives cycle time by approximately twenty to twenty-five percent along with minimizing human error and enhances the production significantly [15].

Sustainability also permeates the entire production process. Waterbased adhesive is being used, and machinery designed for energy efficiency is being employed, which reduces environmental impact with ISO 14001 and enhances responsible and economical manufacturing by making process simpler and thus decrease from all point of views. In conclusion, advanced materials, ergonomic design methods, automated production processes and sustainable practices have significantly improved special footwear quality, safety, and performance. However, there are still challenges such as high first investment costs for machinery and materials. Smart footwear technologies are expected

to evolve in the future by integrating embedded sensors (such as sensors to monitor pressure, temperature and motion), which may enhance user safety, comfort and industrial usability to the next frontier in the future evolution of protective footwear manufacturing.

4. Conclusions

Research in the field of manufacturing technology of special footwear shows that the introduction of new materials, rational footprints and mechanization of production operations in the manufacture of molds for footwear can significantly improve the functional characteristics of products, ensure a high level of safe operation and comfort when wearing shoes. New materials such as polyurethane soles, plastic toe caps, and high-tech fabrics offer rugged durability and protection yet are lighter weight which allow for full freedom of movement and reduced fatigue on the wearer. The ergonomics, developed using computer modeling and Finite Element Analysis (FEA), enables minimal pressure, maximum total shock absorption, to avert injuries and provide all-day comfort. So, investing in automated cutting, stitching, and molding technologies will not just improve production efficiency and precision, they will also help in eliminating material wastages and defects. Use of reusable polymers, biodegradable adhesives, and energy-efficient, low-impact machinery to help footwear production align with global environmental practices (supply, demand, cost, and responsibility effectiveness) can be introduced. Rurak explained a high capital investment in refreshing new machines and goods leads to challenges that continue to be a key roadblock even with a breakthrough technological advancement accomplished. This could be an important research direction for smart footwear with built in sensors to monitor pressure, temperature, and movement to enhance safety and performance. In general, this research validates the need for the adoption of new technological features like modern day material science, design, and manufacturing techniques in the improvement and continuous innovation of special footwear to provide direct work benefits to the end-users and indirect competitive benefits in the international market for associated manufacturers.

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