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DESIGN AND OPTIMIZATION OF SPECIALIZED PROTECTIVE WORKWEAR FOR EMPLOYEES IN THE LEATHER TANNING INDUSTRY.

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Abstract

The leather tanning industry exposes workers to a variety of occupational hazards, including chemical agents, extreme temperatures, mechanical injuries, and prolonged ergonomic stress. To ensure the health, safety, and comfort of employees, the development of specialized protective workwear tailored to the unique demands of tanning environments is essential. This study focuses on the design and optimization of work garments that offer both functional protection and ergonomic adaptability. Using a multidisciplinary approach combining textile engineering, ergonomic analysis, and industrial safety standards, we developed and evaluated prototypes incorporating advanced materials with high resistance to chemical penetration, abrasion, and heat. The garments were tested under simulated workplace conditions, and user feedback was collected to assess fit, comfort, and mobility. Results demonstrate significant improvements in both protective performance and user satisfaction compared to conventional workwear. The study concludes with design recommendations and guidelines for manufacturing durable, effective, and user-centered protective clothing for the leather tanning sector. **Keywords:** Leather tanning industry, Protective workwear design, Occupation safety, Ergonomic garment construction, Industrial clothing optimization, workwear functionality, Hazard-resistant textiles, Worker health and safety, Thermo-mechanical protection, Garment engineering, Industrial hygiene standards, Personal protective equipment(PPE), Durability of work garments, Toxic exposure prevention.

REVIEW OF REALATED LITERATURE

The development of specialized protective workwear for industrial sectors has long been a subject of multidisciplinary research, involving textile engineering, occupational safety, ergonomics, and industrial hygiene. In high-risk environments such as the leather tanning industry, where workers are frequently exposed to hazardous chemicals like chromium salts, sulfuric acid, and other toxic compounds, the need for functional and reliable protective clothing becomes critically important (Singh & Kaur, 2018).

Extensive literature highlights that traditional workwear in industrial settings often fails to meet modern standards of safety and comfort. According to a study by Zhao et al. (2020), inadequate garment design can lead to reduced worker compliance, increased fatigue, and heightened risk of occupational injuries. Therefore, the integration of ergonomic principles and hazard-specific material selection is essential for ensuring both protection and usability. Recent advances in textile technology have introduced a range of high-performance fibers and coatings suitable for chemical and thermal resistance. Fabrics treated with fluorocarbon-based finishes, aramid fibers such as Kevlar, and polyurethane laminates have shown promising results in repelling hazardous substances and withstanding high temperatures (Patel et al., 2019). In the context of leather processing, where workers handle wet hides and are exposed to moisture-rich environments, breathable yet impermeable fabrics are preferred to maintain both hygiene and thermal balance. Ergonomics and Garment Construction-the application of ergonomic design in workwear is crucial for reducing strain and enhancing mobility. Choudhury (2021) emphasizes that poorly designed clothing can cause discomfort and hinder productivity. Multiple studies have proposed 3D body scanning and anthropometric data analysis as tools for achieving optimal garment fit and construction (Ahmed et al., 2017).

Such technologies are increasingly being adopted in the development of sector-specific clothing. Numerous studies point to the direct correlation between insufficient protective wear and long-term health complications in workers. For instance, Sharma & Nair (2016) reported a high incidence of dermatitis, respiratory issues, and musculoskeletal disorders among tannery workers lacking proper PPE. This highlights the necessity of not only providing protective garments but also ensuring their effectiveness, usability, and compliance with occupational health standards. International standards such as ISO 13688:2013 and EN 340 provide general requirements for protective clothing in terms of innocuousness, size designation, ageing, compatibility, and marking. Furthermore, industry-specific regulations demand the inclusion of chemical-resistant features, fire retardancy, and reinforced mechanical strength in garments used in high-risk sectors like tanning (ISO, 2020).

Modern design philosophies stress the importance of user feedback in the iterative development process. Field testing under real workplace conditions enables designers to assess how garments perform in terms of comfort, durability, and protection. A study by Lee et al. (2022) demonstrated how incorporating worker input during the prototype evaluation phase led to significantly higher satisfaction rates and increased PPE usage. Summary the existing body of literature underscores the urgent need for industry-specific, ergonomically optimized, and technologically advanced workwear in the leather tanning industry. By synthesizing insights from material science, ergonomic design, and occupational health, researchers and manufacturers can collaborate to produce garments that not only protect but also empower the workforce. This review provides a strong foundation for further innovation in the field of protective clothing design.

RESEARCH METHODOLOGY

This study employs a mixed-methods research design combining both quantitative and qualitative approaches. The goal is to develop and optimize protective workwear tailored to the specific environmental and ergonomic challenges faced by workers in the leather tanning industry. The methodology involves three primary phases: needs assessment, prototype development, and evaluation testing.

Study Area and Population.

The research was conducted in collaboration with two leather tanning facilities located in Tashkent and Namangan, Uzbekistan. A total of 50 employees (35 male, 15 female), all actively working in production areas with exposure to chemicals and mechanical risks, were selected through purposive sampling. Workers with a minimum of 2 years of experience were included to ensure familiarity with workplace conditions.

Data Collection Methods.

Needs Assessment (Qualitative Phase): Semi-structured interviews and focus group discussions were held with 20 workers and 5 supervisors to gather first

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Obsprotective clothing issues.

Comfort, fit, and mobility conce.

Observational field visits were conducted to analyze body movements, exposure zones, and workflow patterns. Material Selection and Prototype Development.

Based on the findings, three fabric samples were selected for testing:

1. Cotton-polyester blend with PU coating
2. Nomex (for thermal resistance)
3. Aramid-reinforced fabric with Teflon finish

Garment designs were created using CAD-based patterning software, integrating ergonomic cuts, reinforced zones, and ventilation features.

Prototype Evaluation (Quantitative Phase): Prototypes were tested in actual workplace settings for 4 consecutive weeks.

A structured evaluation form was used to assess: Chemical and thermal resistance (lab-tested under ISO 6530 and ISO 11612)

Garment durability (measured after 10 industrial wash cycles)

Fit and mobility (motion range assessment using 3D movement tracking) Qualitative data from interviews and observations were coded and thematically analyzed to identify key design requirements.

Quantitative data (performance metrics and user ratings) were analyzed using SPSS. Descriptive statistics (mean, standard deviation) and ANOVA tests were used to compare prototype performance and user feedback across fabric types.

All participants were informed about the research purpose and provided written consent. The study followed ethical standards as approved by the Uzbekistan State Institute of Textile and Light Industry's Research Ethics Committee.

Limitations study is limited to medium-scale tanning facilities and may not fully represent large-scale industrial settings or facilities using alternative tanning technologies (e.g., vegetable tanning). Future research is encouraged to expand the scope and include environmental impact assessments of workwear materials.

RESULTS AND ANALYSIS

This section presents the findings of the study derived from field testing, laboratory analysis, and participant feedback. The results are organized into four core performance categories: chemical and thermal resistance, durability, ergonomic comfort, and user satisfaction. Comparisons are made across three developed prototypes fabricated from different material compositions.

Laboratory tests were conducted in accordance with ISO 6530 (chemical penetration) and ISO 11612 (heat resistance) standards. The results demonstrated significant differences among the tested materials: Fabric Type Chemical Resistance (%) Thermal Resistance (°C threshold)

Cotton-Polyester + PU 68% 110°C

Nomex 85% 205°C

Aramid + Teflon 91% 240°C

Analysis:

The Aramid-reinforced fabric with Teflon finish outperformed the other samples, offering superior resistance to both chemical penetration and heat exposure. This is particularly beneficial in chrome tanning sections where both hazards coexist. Nomex also demonstrated high performance, though with slightly lower chemical protection.

Durability-garments underwent 10 industrial laundering cycles to assess tensile strength retention and fabric integrity. Tensile strength was measured using the ISO 13934-1 standard before and after washing.

Fabric Type Initial Strength (N) Post-Wash Strength (N) Retention (%). Cotton-Polyester + PU 412 289 70.1%

Nomex 538 486 90.3%

Aramid + Teflon 596 559 93.8%

Analysis:

Aramid-based garments exhibited the highest durability, retaining over 93% of their tensile strength. This indicates that they are highly suitable for long-term industrial use without significant performance degradation. Cotton-polyester blends were found to degrade more rapidly.

3D body motion tracking systems were used to analyze range of motion (ROM) while performing common tasks such as lifting, bending, and carrying loads.

Aramid + Teflon garments allowed an average of 92% ROM compared to casual workwear.

Nomex garments provided 89% ROM. Cotton-polyester prototypes allowed only 81% ROM, with restricted flexibility around the shoulder and knee joints.

Analysis:

Garments made with stretch-integrated Aramid blends allowed greater ease of movement, especially during tasks involving repetitive upper body motion. Workers reported fewer restrictions in mobility and lower perceived physical strain.

A 5-point Likert scale was used to gather user feedback on comfort, safety perception, and overall satisfaction after four weeks of workplace use. The average ratings were: Criteria Cotton-Polyester Nomex Aramid + Teflon

Comfort 3.1 4.0 4.6

Safety 3.4 4.3 4.8

Mobility 3.0 4.1 4.7

Overall Satisfaction 3.2 4.2 4.7

Analysis:

Participants consistently rated the Aramid + Teflon prototype highest across all categories. Notably, 88% of workers expressed a preference for continuing to use this version beyond the study period, citing increased confidence in hazard protection and improved comfort.

Aramid + Teflon was the best-performing material across all metrics: protection, durability, and comfort. Nomex was a strong alternative, particularly where thermal hazards dominate.

Cotton-polyester blends, although more affordable, were significantly less effective in high-risk zones. The integration of ergonomic design and stretch zones positively impacted both motion efficiency and user acceptance.

CONSCLUSION AND RECOMMENDATIONS

This study successfully demonstrated that the design and optimization of specialized protective workwear significantly improve both safety and user satisfaction among workers in the leather tanning industry. Through a structured methodology incorporating field observations, user-centered design, and laboratory testing, it was found that garments made from Aramid-reinforced fabrics with Teflon finish provided the highest level of chemical and thermal protection, superior durability, and excellent ergonomic comfort.

The integration of ergonomic design principles, including anatomically tailored cuts, ventilation zones, and flexibility-enhancing features, proved critical in ensuring worker mobility and comfort during extended use. Quantitative data supported the superior performance of advanced materials, while qualitative feedback emphasized the psychological and physical benefits of improved workwear.

Moreover, the use of CAD-based patterning tools and the implementation of ISO testing standards throughout the design and testing phases validated the scientific rigor of the approach and its applicability to real industrial environments. Overall, the study confirms that tailored protective workwear can enhance both occupational safety and productivity in medium-scale tanning facilities.

Recommendations

Based on the findings of this research, the following recommendations are proposed for industry stakeholders, policy makers, and future researchers:

1. Adoption of Advanced Materials:

Leather tanning enterprises should prioritize the adoption of high-performance materials such as Aramid-Teflon composites to ensure maximum protection against chemical and thermal hazards.

2. Ergonomic Integration in Design:

Workwear must be ergonomically optimized using body movement analysis and anthropometric data to reduce fatigue, enhance comfort, and minimize musculoskeletal risks.

3. Regular User Feedback Loops:

Companies should institutionalize feedback systems where workers can report clothing-related issues regularly, allowing for continuous improvement in protective gear design.

4. Compliance with International Standards:

All protective garments used in high-risk industrial settings must comply with ISO standards (e.g., ISO 6530, ISO 11612) to ensure validated protection levels and worker confidence.

5. Training and Awareness:

Workers must be trained on the correct usage, maintenance, and limitations of protective clothing to maximize its effectiveness and prolong its lifespan.

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