AATCC Foundation 2023 Grant Reports

Analysis of Thermal Comfort Cooling Mechanisms to Combat Heat Stress in the Construction Industry

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Heat stress and heat-related illnesses (HRIs) pose a substantial threat to construction workers and the construction industry. Several compounding issues contribute to this: the strenuous nature of construction work, oppressive hot/humid environments, and long working hours (Acharya, P. et al., 2018). Limited regulations are implemented to protect workers from heat strain. Most U.S Occupational Safety and Health Administration (OSHA) standards related to personal protective equipment (PPE) in the construction industry (OSHA 29 CFR 1926) address safety hazards regarding a physical object rather than thermal comfort and heat strain. With advanced innovations in functional clothing design, incorporating thermal comfort apparel could be a potential measure for preventing heat stress in construction workers (Guo, Y. et al., 2019). With the global cooling fabrics market expected to reach USD 2.6 billion by 2025, more affordable cooling garments and accessories are becoming readily available for the average consumer, making these cooling devices a realistic prevention method for reducing HRIs in the construction workplace (NASDAQ OMX, 2020). Therefore, the purpose of this research was to evaluate the impact of various cooling technology garments based on a construction worker's typical ensemble using a dynamic sweating thermal manikin in combination with thermoregulatory modeling. The researcher evaluated 4 proprietary t-shirts with varying cooling technologies and 2 vests with active cooling pack techniques to determine optimal thermal comfort for construction workers. The predicted physiological responses including the skin temperature (TSK), internal core temperature (THY), sweat rate (SWA), temperature sensation, and comfort perceptions of the human body were analyzed when wearing these cooling technologies during simulated working conditions that replicated the metabolic work rate of construction employees. Results demonstrated a significant decrease in TSK and SWA for both vests with cooling packs and SHIRT2 with ventilated fabric construction. Each cooling device showed negligible differences in THY, which was not surprising considering the high activity level and environmental conditions in the testing protocol. SHIRT2 was shown to be the most "comfortable", and VEST1 and VEST2 resulted in the coolest perception for predicted temperature sensation. These findings support the use of cooling technologies in construction work PPE and apparel. To the researchers' knowledge, this work is the first of its kind to combine optimal cooling fabric technologies for assessment during a simulated construction workday in high temperature conditions (>35°C) on a dynamic sweating thermal manikin.

Comparing current consistency and electrical resistance of wearable photovoltaic cells pre- and post-laundering and pre- and post-corrosion resistance testing conditions

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An investigation of the current consistency and electrical resistance test of wearable Photovoltaic cells under laundering and corrosion testing conditions for marine settings. Abstract: This research project aimed to compare the maximum current consistency in ampere (amp) and electrical resistance of commercially sourced wearable PV cells pre- and post-laundering and corrosion resistance testing conditions. Results from this study open the potential for the extensive library of currently overlooked testing results for wearable PV cells to be used as a reliable source for lowering electronic devices such as mobile phones in the marine environment. The following objectives guided the research study: (1) to baseline measure the current capacity and electrical resistance (AATCC EP13) for 1W flexible wearable photovoltaic cells direct from manufacturers; (2) evaluate the corrosion aspects (ASTM B-117-19) and compare post-corrosion current capacity and electrical resistance; (3) compare current capacity and electrical resistance to baselines following five home laundering cycles (ISO 6330:2000). Results from this study will provide researchers and product developers with valuable information on the reliability of wearable PV cells for occupational use in a marine environment.

Bacterial Cellulose as a Sustainable Bio-Textile: Developing Sustainable Leather with Emphasis on Improved Properties

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In terms of creating the bacterial cellulose textile, we continued with the process of Kombucha fermentation as a way to compare differences and consistencies of the resulting textiles. The steps of this method include brewing tea and mixing it with varying ratios of glycerin and sugar per sample (to compare results), with a S.C.O.B.Y (symbiotic culture of bacteria and yeast) placed in each sample beaker to watch its development. Glass beakers were opted in place of the original plastic container used for material growth as we introduced powdered dyes to see if it affected the coloration of the material. Attempts to extend the variety of colors of the textile consisted the addition of a growth medium such as indigo, turmeric, osage, and cochineal powders to the fermenting culture. The results were inconsistent with some materials being successfuly colored while others showed signs of not sticking to the material or failing to integrate entirely, causing the material to suffer in growth. Future plans of creating inherently colored material includes revisitation/modification of the culture preparation process to continue experimenting with color.

Additionally, we also focused on the development of hydrophobic finishes. The first attempt involved two different ways of applying two different waxes, one being beeswax and the other being a wax containing plant oils. The experiment was laid out with five samples; a control sample was used to measure the time it would take untreated material to absorb water and observe the reaction of the material, the rest were treated by brushing on melted wax or rubbing it on the sample. In our test we saw that rubbing the wax on the sample was more effective in preventing water absorption than brushing it on. The plant oil wax was more effective. Future plans and tests involve 3D printing a thin layer of PLA on the textile as well as blending corn ingeo fibers with the textile via heat pressing. Currently we are observing the growth of larger material in new container sizes, viewing if the bacterial cellulose growth throughout the material is consistent. By doing so, we are confirming whether our ingredient/production ratios are accurate and reliably interchangeable with various container sizes.

Development of Medical Textiles with Nanofibrous Bioactive Coating for Wound Healing

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Carvacrol is a monoterpenoid molecule found in the essential oils of oregano, thyme, and other plants. It has well known antimicrobial, antioxidant, and anticancer properties and shows promise in clinical applications (e.g. wound healing). However, carvacrol is highly volatile and has low water solubility, therefore its use could be limited due to its low bioavailability, instability, and low shelf-life when carvacrol is used as antimicrobial and antioxidant agent. Cyclodextrin (CD) are non-toxic, cyclic oligosaccharides that enhance thermal stability and water solubility of encapsulated molecules due to inclusion complexation (IC). In this study, carvacrol CD-IC were incorporated in chitosan nanofibers via electrospinning. Chitosan, a natural non-toxic polymer, is known for its inherent antimicrobial properties. The chitosan/carvacrol CD-IC nanofibrous coating was electrospun onto a nonwoven cotton patch. The CD-IC will preserve carvacrol and increase its shelf-life and will increase its solubility and therefore bioavailability. The cotton patch functionalized with chitosan/carvacrol-CD-IC nanofibers will have antimicrobial and properties and have potential use for wound healing and medical textiles.

Performance evaluation of wearable smart socks to collect physiological data from diabetes patients

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Smart textiles, particularly in the realm of medical wearables, have garnered significant attention for real-time data collection to improve personal healthcare. However, challenges persist in the fabrication and longevity of soft, textile-based electrodes and sensors, often resulting in discomfort and discontinuation of use. This project addresses these challenges through the development of a

"Smart Sock PPE" designed to gather targeted physiological parameters, specifically foot pressure and temperature, for the early detection and prevention of foot ulceration. The primary focus is on individuals affected by diabetes, a condition impacting 37.3 million Americans (Center for Disease Control and Prevention, 2022), where high pressures can lead to foot ulcers (Najafi et al., 2017). Existing electronic sensors have faced limitations in terms of wearer comfort due to uneven fabric connections (Dragulinescu et al., 2020; Rotzler et al., 2021). In response, the proposed smart sock integrates advanced sensing technologies, data acquisition, and transmission modules, emphasizing nonirritating quality, greater comfort, and reusability. In addition, the sock incorporates motion sensors for comprehensive gait and motion tracking, contributing to detailed data collection for medical wearables. The project aims to monitor plantar pressure and temperature simultaneously, enabling early detection of at-risk plantar regions (Najafi et al., 2017). The gathered data could be communicated to the wearer/user and/or personal care physician through a Bluetooth application. Statistical analysis using SPSS with a significance level of $P < .05$ has been employed to establish the relationship between foot pressure and temperature and detect patterns indicative of potential ulceration.

Current limitations in smart textiles, such as metallization loss and discomfort (Rotzler et al., 2021), will be addressed through advancements in e-textile performance capabilities. The "Smart Sock PPE" seeks to contribute to health status awareness among a broader audience, promoting proactive measures to reduce pain and stress associated with prolonged standing. The project aims to enhance foot health and overall well-being by seamlessly incorporating awareness into a performance-level sock. Ultimately, this innovative solution aligns with the evolving landscape of medical wearables, offering a promising avenue for preventive healthcare interventions.

Mechanical and morphological properties of cellulose nanocrystals synthesized from industrial hemp agro-waste

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The rapid increase of industrial hemp growth in the US has resulted in a significant increase of hemp agro-waste, suggesting a need of counteracting the increasing agro-waste and promoting sustainable farming practice. One attractive solution is to treat hemp agro-waste with ammonium persulfate (APS), resulting in cellulose nanocrystals (CNCs) which are biofriendly and environmental-friendly alternatives to petroleum-based materials. However, most existing work on CNC extraction focuses on other cellulose sources such as cotton, wheat, and rice. There has been a lack of work on hemp, particularly hemp agro-waste using APS treatment. In this study, the one-step treatment was followed by purification to remove impurities and hence to colloidally stabilize CNCs in aqueous solutions. The resulting CNCs had an average length of 190 nm and average height of 4 nm. The mechanical analysis of individual CNCs using Force-Distance Spectroscopy suggested a Young's modulus of 2.19 ± 0.15 GPa, maximum loading force of 6.29± 0.09 nN, and adhesion energy of 1.57 ± 1.12e-16 J. No statistical differences between purified and unpurified

CNCs were found in Young's modulus and maximum loading forces measurements, suggesting the impurities had minimum impact on mechanical strength. The results highlight hemp agro-waste as a valuable resource and the one-step APS treatment as an eco-friendly and efficient method to produce CNCs.

Characterizing the Thermal Protective Performance of Protective Textiles under Flame Exposure

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The study assessed flame exposure effects on thermal protection in single and multi-layered high-performance fabrics with varying air gaps. Testing three flame intensities and air gap sizes revealed thicker fabric layers enhanced protection by creating longer heat transmission paths through air layers. Larger air gaps reduced heat transferred to fabric in different heat fluxes, but above stagnant air condition i.e., over 6 mm didn't notably improve protection due to the initiation of convection heat transfer. Hence, while air gaps generally enhanced protection, stagnant conditions impacted their effectiveness. This research highlights how hazards and clothing factors influence thermal protection, aiding the development of more effective protective gear for firefighters.

Foam-Fiber Biotextile Composite Scaffolds for Tissue Engineering

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Tissue Engineering and regenerative medicine aim to create functional human tissues or organs using cells on scaffolds. TE scaffolds address the clinical need to repair or replace damaged tissues due to diseases, genetic issues, or injuries. Traditional scaffolds face limitations, like balancing porosity and strength. This research project focuses on biotextile composite scaffolds: polymer foam with controlled pore size and interconnectivity, reinforced by fibers or yarn. The foam provides a large surface for cell growth, while fibers offer structural reinforcement, stiffness adjustments, and surgical attachment points. These scaffolds initially target skin tissue replacement for trauma or burns but can adapt for other tissues like connective or dental tissue. The aim is to create versatile scaffolds for tissue engineering by combining foam and fibers, enhancing cell growth and offering mechanical support for various tissue types beyond skin regeneration.

The Impact of Disperse Dyes and ageing on microfiber shedding propensity of polyester fabrics during laundering

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Microplastic pollution is a recent environmental issue focused on by both marine and textile researchers. Many reports have shown that more than 80% of the microplastics found in the ocean and seabed are microfibers from textiles. Microfiber shedding is the loss of loose or damaged fibers from the surface of textile materials. The shedding phenomenon from the surface occurs during the usage phase, the laundry process has been identified as a cause of microfiber shedding due to agitation from the machine and abrasion against other fabrics. Polyester is a fiber of interest as it accounted for more than 50% of the synthetic fibers production of U.S. synthetic Fiber Market in 2021 and known not to easily or quickly degrade. It had been reported that many of the microfibers released in the laundry effluents are Polyester. Although there has been some research looking at microfiber shedding from polyester fabrics, these studies have focused primarily on laundering parameters and fabric characteristics. However, the microfiber-shedding phenomenon, as impacted by dyes and aging, has not been studied in detail. The Microfibre Consortium recently identified this as a key area of interest.

The focus of this research is to study the microfiber shedding propensity of dyed vs. undyed polyester fabric and to also evaluate the effects of UV light exposure and heat on these fabrics. It has been shown in some cases that the chemical structure of dye molecules, chromophore and auxochrome groups, if unstable, can result in fiber degradation, which may cause the acceleration and increase of microfiber shedding from the dyed fabrics during laundering. In addition, fabric exposure to heat and UV light can also lead to accelerated fiber degradation, resulting in accelerated and increased microfiber shedding over the life of the product. This study aims to evaluate the impact of various dye categories within the disperse dye class and the effect of UV light exposure and heat on fiber shedding propensity. The quantity of fibers shed during laundering will be determined along with fabric characterization for evaluations for strength, elongation and abrasion, and fiber molecular weight before and after multiple exposures to heat, light and laundering. This will provide insight as the interaction between normal use and care, the dye and fiber interaction to see if selection of dyes or color has a significant impact on this.

A Sustainable Textile Biomaterial with Antimicrobial Properties-Cellulose Fiber Infused with Nanosilver

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Cellulose, a natural and renewable resource derived primarily from plant cell walls, has gained significant attention as a promising textile biomaterial. While various fabrication methods exist, the one used in this study is the wet-spinning process. The wet-spinning process is a cost-effective process known to enhance the mechanical properties of natural fibers. During wet-spinning, cellulose solution is submerged in a coagulating bath and formed into the fiber structure, while strengthening the hydrogen bonds between nanofibers. The process was conducted using a Micro Wet Spin Tester, allowing for precise control over fiber production.

Looking ahead, the potential for improving cellulose filament properties and expanding their utility in various applications, particularly in the fashion and textile industries, is promising. Utilizing raw recycled or agricultural materials to create new cellulose filaments presents an avenue for exploring their properties and broadening their applications.

In addition to these advancements, the study delves into the incorporation of nanomaterials into cellulose fibers, specifically nanosilver, to infuse them with antimicrobial properties and enhance their utility as biomaterials. Nanosilver is recognized for its effectiveness as an antimicrobial agent, interfering with bacterial DNA replication and disrupting bacterial proteins in cells and cell walls. This study demonstrates the potential to harness the antimicrobial properties of nanosilver within cellulose fibers, making them suitable for use in medical textiles and personal textile applications.

The wet-spinning process for cellulose-nanosilver composite fibers is conducted using the Micro Wet Spin Tester (WST-M). The fibers, mechanical and physical properties are examined through various testing methods, including Scanning Electron Microscopy (SEM), Thermogravimetric Analysis (TGA), and tensile strength testing. Experimental outcomes from this research could help understand the wet spinning mechanism of functional cellulose filament fiber formation and lead to further research on improving the wet spinning process for producing commercial quality antimicrobial cellulose fibers.

In conclusion, this study offers a comprehensive investigation into the enhancement of cellulose as a sustainable textile biomaterial with antimicrobial properties. It applies the – special wet-spinning technique to combine micro/nano cellulose, nanosilver, and alginate biomass to produce cellulose composite fiber. Advanced testing methods are used to evaluate the cellulose composite fibers properties with significant potential for various textile applications.

Fabrication of Reusable, Biocidal, and Biodegradable Nanofibrous Membranes for Future N95 Masks

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Current facemasks and respirators are made of petroleum-based meltblown and spunbond polyolefin nonwoven fabrics, which serve as filtering materials effectively blocking penetration of infectious particles and droplets on the outside surface. These masks are single use and nonbiodegradable leading to concerns of environmental pollution and potential cross-contamination if the used products are not properly disposed. Aimed at the development of reusable, biodegradable, and biocidal materials for the next generation of facemasks and respirators. The biobased and biodegradable polylactic acid (PLA), as an alternative of the olefin polymers, was employed in the research and electrospun to fibrous membranes to concept-prove the technical feasibility in this study. Both fibrous nonwoven structures and incorporation of a daylight-active and edible photosensitizer (Vitamin K3- VK3), as a biocidal additive into PLA (PLA/VK3) were conducted. In a lab-scale concept-proofing study, PLA or PLA/VK3 electrospun fibrous webs were directly deposited onto a PLA spunbond nonwoven fabric and highly porous and biologically functional nonwoven materials were successfully prepared. The developed nonwovens revealed promising results of desired filtering efficiency against small particles with low pressure drop, efficient generation of Reactive Oxygen Species (ROS), and antibacterial functions under daylight exposure.

Novel mesh formulation for targeted delivery of chemotherapeutic drugs

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Desmoplastic small round cell tumor (DSRCT) is an uncommon and aggressive sarcoma that primarily affects teenagers and young adults. Most recurrences occur in the abdomen, and the disease-free survival rate frequently falls below one year. Hyperthermic intraperitoneal chemotherapy (HIPEC), an efficient local control therapy for sarcoma, is employed as the treatment strategy after the tumors surgically removed. This study aims to formulate a chemotherapeutic drug-releasing mesh that complies with the requirements of the treatment protocol. To extend the local control of sarcoma, the drug-releasing mesh will be implanted in the abdominal cavity, which will release the chemotherapeutic drug to eradicate any remaining cancer cells. The mesh should be able to release the drug until the post-operative scar tissue is formed, which is approximately two weeks. Studies will be conducted to evaluate the structure of the mesh, its degradation time, its mechanical and chemical stability, the uniformity of the surface distribution of the drug, the drug-elution rate, and other factors. The mesh's effectiveness in releasing the drug in vitro will be assessed using cancer cell models. The results of this study will provide important data for the localized and controlled release of chemotherapeutic medicines, which have the potential to be used clinically in the DSRCT treatment protocol after proper in-vivo assessments and human trials.

Separation of reactive dyes, disperse dyes, cellulose and polyethylene terephthalate from poly/cotton blends for complete circulation of waste textiles

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This project aims to develop a safe and efficient technology to separate reactive dyes, disperse dyes, cellulose, and polyethylene terephthalate from waste polycotton textiles. The chemical structures of polymers and dyes are not damaged after the separation. The pure and colorless polymer and dyes can be reused. Among all types of textile fibers, cotton and polyester fibers are dominant worldwide. Current technologies only allow direct reuse of garments or uncolored fibers from wastes. Here, dyed polyester was dissolved and separated from the blend, followed by controllable polyester precipitation to retain its dyes separately in the solution. The remaining-colored cotton was swollen to remove its dyes after cleavage of dye-cellulose bonds. Colorless polyester and cotton were regenerated into fibers with similar and 60% higher tenacity than those before the recycling, respectively. Recycled fibers also had desirable dyeability, including dye exhaustion and colorfastness, after being dyed with the dyes extracted from the polyester/cotton blends, via our newly developed solvent dyeing system. More than 99% of the solvent used in the recycling was recycled. Our recycling had a cost and energy consumption of less than 20% of the production of virgin materials.