# Thermal Conductivity Optimization for Arthritic Knee Braces

Chloe Tutunick and Allie Walters

Florida State University Panama City

## Abstract

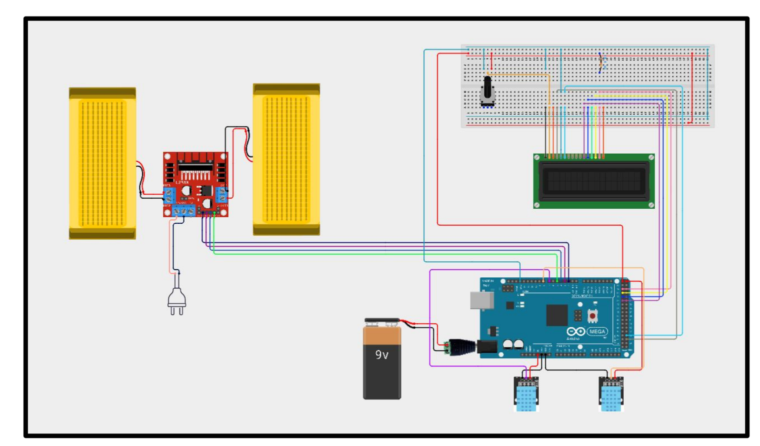
This project evaluates the thermal properties of a Lycra-Nylon composite for its potential use in therapeutic knee braces for osteoarthritis pain relief. Simulations and experiments were conducted to assess the material's thermal conductivity and diffusivity. MATLAB simulations identified the composite as optimal for controlled heat transfer, while experimental results using Arduino-based setups validated its thermal conductivity (0.56 W/m·K). These findings confirm the material suitability for maintaining stable temperatures (104–113°F), crucial for therapeutic applications.

## Introduction

Heat transfer fundamentals, particularly thermal conductivity ($k$) and thermal diffusivity ($\alpha$), were central to this analysis, as they play a critical role in temperature regulation within wearable materials. Conductivity governs heat transfer, determining how effectively a material insulates or cools, while diffusivity dictates how quickly a material responds to temperature changes. These properties are especially relevant for therapeutic knee braces, which require materials with moderate thermal conductivity and low diffusivity to maintain consistent, comfortable heat for pain relief. This project focused on evaluating the Lycra-Nylon composite for its potential use in such applications, with key metrics including thermal conductivity, diffusivity, and stability during extended use. To assess the composite's suitability, its thermal properties were compared with those of industry-standard materials such as Neoprene (a synthetic rubber) and Gore-Tex (expanded polytetrafluoroethylene), both commonly used in wearable devices. The analysis prioritized materials that exhibit moderate thermal conductivity and low diffusivity. These are ideal characteristics for controlled and stable heat transfer. By examining these properties across all three materials, the study aimed to determine the viability of the Lycra-Nylon composite for wearable medical applications.

## Methods

- Simulations: MATLAB and Arduino were used to model thermal conductivity and diffusivity for Lycra-Nylon and other materials.
- Experimental Setup: Arduino systems with DHT11 sensors recorded real-time temperature changes in the composite encasing a heating element.




```
% Display the results for thermal conductivity
fprintf('Thermal Conductivity Results (W/m*K):\n');
fprintf('Neoprene: %g W/m*K\n', thermal_conductivity_neoprene);
fprintf('Gore-Tex (ePTFE): %g W/m*K\n', thermal_conductivity_goretex);
fprintf('Lycra-Nylon Composite: %g W/m*K\n\n', thermal_conductivity_lycra_nylon);

% Thermal Diffusivity Calculation
thermal_diffusivity_neoprene = thermal_conductivity_neoprene / (density_neoprene * specific_heat_neoprene);
thermal_diffusivity_goretex = thermal_conductivity_goretex / (density_goretex * specific_heat_goretex);
thermal_diffusivity_lycra_nylon = thermal_conductivity_lycra_nylon / (density_lycra_nylon * specific_heat_lycra_nylon);

% Display the results for thermal diffusivity
fprintf('Thermal Diffusivity Results (m^2/s):\n');
fprintf('Neoprene: %g m^2/s\n', thermal_diffusivity_neoprene);
fprintf('Gore-Tex (ePTFE): %g m^2/s\n', thermal_diffusivity_goretex);
fprintf('Lycra-Nylon Composite: %g m^2/s\n', thermal_diffusivity_lycra_nylon);

% Based on outputs Lycra-Nylon seems to be the best fit for a knee brace
% as it has Lowest CTE, which offers better dimensional stability with temperature changes.
% Lowest thermal conductivity, providing superior insulation and warmth retention.
% Its slightly higher thermal diffusivity is still within a reasonable range, ensuring comfort without drastic temperature shifts.
```

## Results

- Simulated Properties: The Lycra-Nylon composite exhibited a thermal conductivity of 0.23 W/m·K and low diffusivity, $1.21*10^{-7}$ $m^2/s$, ideal for heat retention.
- Experimental Findings: Conductivity was experimentally measured at 0.56 W/m·K, slightly higher than simulated values but within acceptable ranges for wearable applications. Diffusivity measured to be $2.94*10^{-7}$ $m^2/s$, a higher value but still supports uniform heat transfer.
- Observations: The material maintained consistent heat distribution without degradation or hotspots, demonstrating its potential for therapeutic use.

## Discussion

- Thermal Conductivity: Experimental value was higher than the theoretical value of due to assumed negligible heat losses.
- Thermal Diffusivity: Experimental value was higher than the theoretical value possibly due to experimental, environmental heat loss and ideal theoretical values used.
- Significance: Despite discrepancies, the composite met requirements for controlled heat transfer and stability. Enhancements in experimental design and material property measurements can reduce these variances. Overall, the results support the Lycra-Nylon composite as a viable material for therapeutic knee braces.

### Conclusions

- Successful Hardware Setup: The Arduino-based hardware setup effectively measured temperature differences inside and outside the Lycra-Nylon composite, providing reliable real-time data for analysis.
- Material Validation: The Lycra-Nylon composite demonstrated favorable thermal properties.
- Consistent Heat Transfer: The material effectively maintained stable and uniform temperatures in the desired therapeutic range (104–113°F).

## References

1. Callister, W.D., & Rethwisch, D.G. (2010). Materials Science and Engineering: An Introduction. John Wiley & Sons.
2. Çengel, Y.A., & Ghajar, A.J. (2020). Heat and Mass Transfer: Fundamentals and Applications. McGraw-Hill Education.
3. Martin, N. A., & Falder, S. (2017). A Review of the Evidence for Threshold of Burn Injury. ScienceDirect, from https://doi.org/10.1016/j.burns.2017.04.003
4. My Engineering Tools. (n.d.). Thermal Conductivity of 300+ Common Materials.
5. W.L. Gore & Associates. (2023). GORE Thermal Insulation: Technical Note.