NED University of Engineering and Technology

Final Year Project Showcase Batch-2020
Year 2024

Department: Textile Engineering Programme: Textile Sciences	
1	**Project Title** Experimental Investigation and Numerical Modelling of Sensing Behavior of Single Jersey Knitted Strain Sensors
2	**Project Idea** The primary goal of this project is to explore and understand the sensing behavior of single jersey knitted strain sensor (SJKSS) through both experimental investigation and numerical modeling. This includes characterizing its mechanical and electrical properties, developing models to predict its behavior under different stitch lengths/settings, and validating these models against experimental data. This idea is viable for the application of comfortable textile-based strain sensors to be used in monitoring of human body respiratory efforts and joint motions.
3	**Process** In this project, we explored the effect of stitch settings on the sensing behavior of SJKSS through a comprehensive methodology. 1)It started with a literature review to gain insights into existing research in weft knitted strain sensors and finding of the research gap, 2) 32 SJKSS samples were fabricated on a computerized flatbed knitting machine in our departmental lab by Varying the stitch settings of conventional (elastomeric) and conductive yarns between 20 and 60. 3) All fabricated samples were tested on a customized test rig and results were analyzed in terms of sensitivity, linearity, and hysteresis for comprehensive assessment of sensing behavior of SJKSS. 4)Following this, COMSOL Multiphysics® was employed to simulate and model the plain weft knit structure, creating a unit cell that accurately represents the fabric by extracting constructional parameters from image analysis and material properties from the actual sensors to create parametric 3D models that replicate the sensors' behavior. 5)FEM analysis was performed on the developed 3D models to simulate the electro-mechanical behavior of the three selected samples from the total 32 samples for detailed analysis and validation. 6)The 3D simulation models were validated by comparing the simulated results with the experimental data. 7)Models were optimized as needed to ensure accuracy in predicting the electro-mechanical performance of the SJKSS. 8)Results of both the experimental testing and FEM simulations were compared in order to draw the conclusion in terms of sensitivity, linearity, and hysteresis.
4	**Outcome** The sensing behavior of knitted strain sensors were predicted through physical experimental testing as well as computational analysis. Excellent sensing behavior achieved of some investigated samples through both physical experimental testing and 3D numerical modelling. Parametric analysis was done to analyze the relationship between the structural parameters and the sensing behavior. Comparisons were also made between the experimental results and the simulated outcome which were found to be highly correlated. It was concluded that stitch settings of both conductive and non-conductive yarns play a crucial role in producing highly sensitive weft knitted strain sensors.

5	**Evidence (Theoretical Basis)** The focus of this research is to carry out the detailed investigation of sensing behavior of Single Jersey Knitted Strain Sensors (SJKSS) by changing the stitch settings of conductive and non-conductive courses and also perform the simulation modelling to validate and evaluate the electro-mechanical behavior of SJKSS. In medical, for monitoring and analyzing the healthcare parameters, textile sensors are becoming a popular area of interest in recent times. They have been applied for monitoring ECG, respiration rate, Human Pulse rate, joint movement, foot pressure and other physiological Parameters of the human body. The simulation results were validated by comparing them with the experimental data obtained from the test rig. The close agreement between the simulated and experimental results confirmed the accuracy of the developed models, demonstrating their reliability in predicting the behavior of SJKSS. Copies of the literature review, sample fabrication records, experimental data, simulation model files, FEM analysis results, and the final project report are available as evidence of the project's completion and the validity of its findings.
6	**Competitive Advantage or Unique Selling Proposition** **<u>Competitive Advantage:</u>** 1) **Integration of Predictive Modelling with Experimental Validation**: This project uniquely combines advanced computational modeling with thorough experimental validation, providing a deep understanding of the sensing behavior of Single Jersey Knitted Strain Sensors (SJKSS). Unlike other research groups (as per literature review) who may rely solely on experimental methods or basic modeling, this integrated approach ensures more accurate predictions and optimizations, leading to superior sensor performance. 2) **Customizable Sensor Design:**The project allows for the customization of sensor properties by modulating stitch settings and material choices. This flexibility enables the design of sensors tailored to specific applications, whether in wearable electronics, health monitoring, or soft robotics. 3) **Pioneering 3D Simulation Models:** The development of novel 3D computational simulation models for SJKSS, which incorporated real material properties and constructional parameters, is a cutting-edge approach that few competitors have adopted. These models provide new insights into the electro-mechanical behavior of knitted sensors. 4) **Enhanced Cost Efficiency:** By reducing material waste, automating processes, and optimizing sensor designs through simulation, the project achieves significant cost efficiencies. These savings can be passed on to customers, making the sensors more affordable without compromising quality. 5) **Comprehensive Understanding of Sensor Behavior:**The thorough investigation into the factors influencing sensor behavior, such as sensitivity, linearity, and hysteresis, leads to a more robust and reliable product. This deep knowledge is leveraged to continually improve and refine sensor performance. **<u>Unique selling proposition</u>** 1) The ability to accurately predict and optimize sensor behavior before physical fabrication reduces development time and costs, offering a high-performance product at a competitive price.

	2) Offering a customizable sensor design that can be tailored to meet specific application requirements provides a significant edge over standardized, one-size-fits-all competitors. 3) The project's ability to deliver highly consistent and reliable sensor performance sets it apart in industries where precision and reliability are critical, such as medical devices and wearable technology. 4) The project’s use of advanced 3D simulation models not only enhances product development but also positions it as a leader in innovation, attracting clients seeking the latest technology in textile-based sensors. 5) Offering high-quality, advanced sensors at a lower cost due to the project’s efficient processes provides a compelling value proposition in a competitive market.
a	**Attainment of any SDG** **<u>SDG 3: Good Health and Well-being</u>** 1) **Wearable Health Monitoring**: Strain sensors integrated into wearable textiles can monitor health parameters such as posture, respiratory rate, and movement, enabling early detection of health issues and continuous health monitoring. 2) **Remote Patient Monitoring**: Can aid in telemedicine by providing real-time data to healthcare providers, improving the management of chronic diseases and reducing the need for frequent hospital visits **<u>SDG 8: Decent Work and Economic Growth</u>** 1) **Innovation-Driven Employment**: The development and commercialization of advanced smart textiles and strain sensors can create new jobs in research and development, manufacturing, and quality assurance within the tech and textile industries. 2) **Industry Growth**: The integration of smart textiles into various industries such as healthcare, sports, and civil engineering can stimulate growth in these sectors, leading to increased demand for related products and services.
b	**Any Environmental Aspect** **Optimized Manufacturing**: The insights gained from numerical modeling can lead to more efficient manufacturing processes, minimizing resource consumption and waste generation
c	**Cost Reduction of Existing Product** In this research computational analysis was used which is the best approach for analyzing sensing behavior of knitted strain sensors because experimental testing can be time consuming and also cost incurred of (material, machine and energy) in physical sample development.
d	**Process Improvement which Leads to Superior Product or Cost Reduction, Efficiency Improvement of the Whole Process** (e.g. What is the issue is current process and what improvement you suggests) **<u>Current process issues</u>**

1) High Material Costs: The use of specialized conductive materials, such as silver-coated nylon yarn, contributes to high material costs in the production of SJKSS. Additionally, the trial-and-error approach in determining optimal stitch settings leads to material wastage.
2) Time-Intensive Fabrication Process: The current process of manually adjusting stitch settings on a computerized knitting machine for each sample is time-consuming. Each variation requires separate setup and calibration, leading to extended production times.
3) Inconsistent Sensor Performance: Variability in sensor performance, such as sensitivity, linearity, and hysteresis, arises from inconsistencies in the fabrication process, particularly in maintaining uniform tension and stitch settings during knitting
4) Labor-Intensive Testing and Validation: The process of testing and validating the sensors on a customized test rig is labor-intensive and requires manual data collection and analysis, which can introduce errors and inconsistencies.

Improvement Suggestion

1) Implement a predictive modeling approach using computational simulations prior to physical fabrication. By simulating the performance of various stitch settings and material combinations, the optimal configuration can be identified before production, reducing material waste and overall costs.
2) Introduce automation in the knitting machine setup process. By developing a programmable system that automatically adjusts the machine settings based on pre-determined parameters, production efficiency can be significantly improved, reducing the time required for sample fabrication.
3) Integrate real-time monitoring and feedback control systems into the knitting machine. These systems would continuously monitor tension and stitch consistency, automatically adjusting parameters to maintain uniformity. This would lead to more consistent sensor performance across different batches.
4) Develop and implement automated testing rigs equipped with sensors and data acquisition systems that can perform real-time data analysis. Automating the testing process not only increases accuracy but also reduces labor costs and accelerates the overall development timeline.

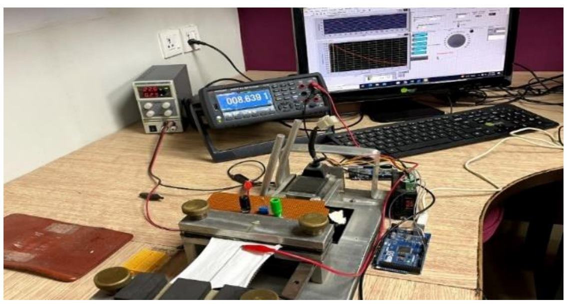
Benefits

1) Cost Reduction: By optimizing material usage through predictive modeling and reducing waste, overall material costs can be significantly lowered. Automation of the fabrication and testing processes will also reduce labor costs.
2) Efficiency Improvement: Automating the knitting setup, real-time monitoring, and testing processes will drastically reduce production time, allowing for quicker iterations and faster time-to-market.
3) Product Quality: Consistency in sensor performance will be improved by maintaining uniform tension and stitch settings throughout the fabrication process, leading to a superior product with reliable and predictable behavior.

	4) Scalability**:** A streamlined and automated production process will enable easier scaling from prototype to mass production, ensuring that the sensors can be produced in larger quantities without compromising quality.
e	**Expanding of Market share** The growing wearable technology market, particularly in health and fitness monitoring, presents a significant opportunity. SJKSS can be marketed as a key component in smart garments that monitor vital signs, posture, and movement in real-time. The demand for non-invasive, flexible sensors in medical applications is rising. SJKSS can be integrated into medical devices for patient monitoring, rehabilitation, and remote health tracking. The soft robotics industry is expanding, with applications in automation, prosthetics, and assistive devices. SJKSS can serve as a crucial sensing element, providing feedback on movement and pressure. Partner with textile manufacturers to integrate SJKSS into existing fabric lines, enabling the production of smart textiles at scale. This can also include co-development of new textile products that incorporate SJKSS technology.
f	**Capture New Market** (e.g. Niche market or unaddressed segment) Develop partnerships with sportswear brands to integrate SJKSS into athletic clothing. These sensors can monitor muscle strain, posture, and movement during workouts, providing athletes with real-time feedback to optimize performance and reduce injury risk. Collaborate with rehabilitation centers and physical therapists to create smart rehabilitation garments. SJKSS can track patient movements, ensuring exercises are performed correctly and providing data for progress tracking. Introduce SJKSS into industrial workwear to monitor worker posture, fatigue, and strain, helping to prevent workplace injuries. This can be particularly valuable in physically demanding jobs like construction, mining, and logistics
g	**Any Other Aspect**
7	**Target Market** **1. Healthcare and Medical Devices** • **Wearable Health Monitoring**: Manufacturers of wearable health devices can integrate these strain sensors into clothing and accessories to monitor vital signs, posture, and movement. • **Rehabilitation**: Medical professionals can use garments with embedded strain sensors for monitoring patient progress in rehabilitation. **2. Sports and Fitness** • **Athletic Apparel**: Companies producing sportswear can incorporate strain sensors into their products to track performance metrics such as muscle activity, movement efficiency, and strain. • **Fitness Tracking**: Developers of fitness trackers and smart apparel can use these sensors to provide more accurate data for users. **3. Textile and Fashion Industry** • **Smart Clothing**: Fashion brands looking to innovate with smart textiles can integrate strain sensors to add functionality to their garments. • **Adaptive Clothing**: Manufacturers of adaptive clothing for people with disabilities can use strain sensors to create garments that respond to movement and provide better support. **4. Automotive and Transportation** • **Vehicle Safety Systems**: Automotive companies can use these sensors in seats and interiors to monitor driver posture and fatigue, enhancing safety.

8	**Team Members** (Names along with email address)	Hafiza Tazeen Mahmood mahmood4302640@cloud.neduet.edu.pk Muhammad Imshal imshal4303691@cloud.neduet.edu.pk Fardan Mehmood mehmood4303833@cloud.neduet.edu.pk Bushra Khan khan4302530@cloud.neduet.edu.pk
10	**Supervisor Name** (along with email address)	Prof.Dr.Muhammad.Dawood Husain dawood@cloud.neduet.edu.pk Dr. Owais Raza Siddiqui orazas@cloud.neduet.edu.pk
11	**Video (If any)**	https://drive.google.com/file/d/167nY5Nxa3BmiEefSgeZvwks2zi5-o2Zt/view?usp=drive_link

Pictures (to be pasted below


(a)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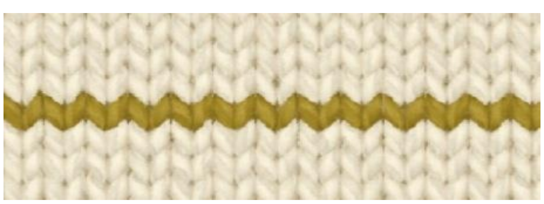
(c)


(d)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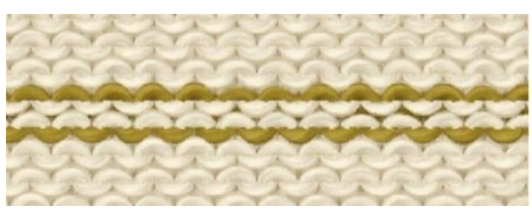
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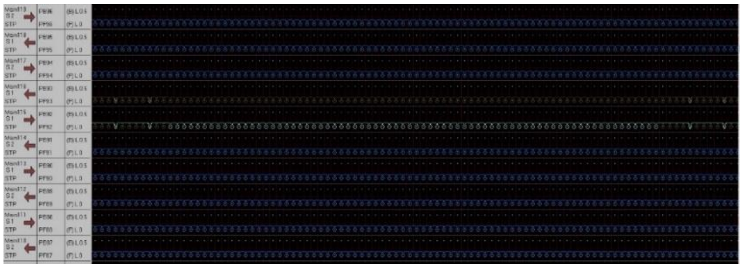
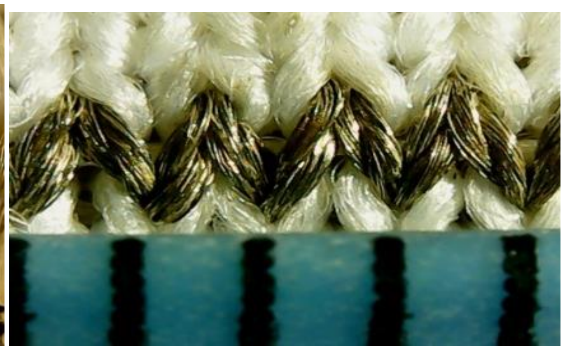


(g)

(h)

a) Gauge Factor Test Rig and Multimeter, b) 24-gauge Flatbed knitting machine (SSR 112) by Shima Seiki, c) Fabric view front, d) Fabric view back, e) knitted loops view front f)knitted loops view back g) Needle view/Technical view, h) Needle view close

(a)



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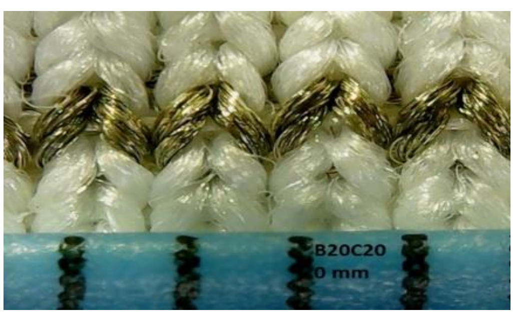

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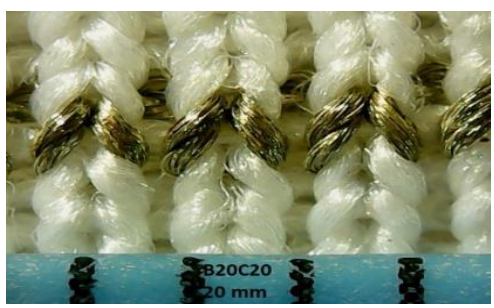
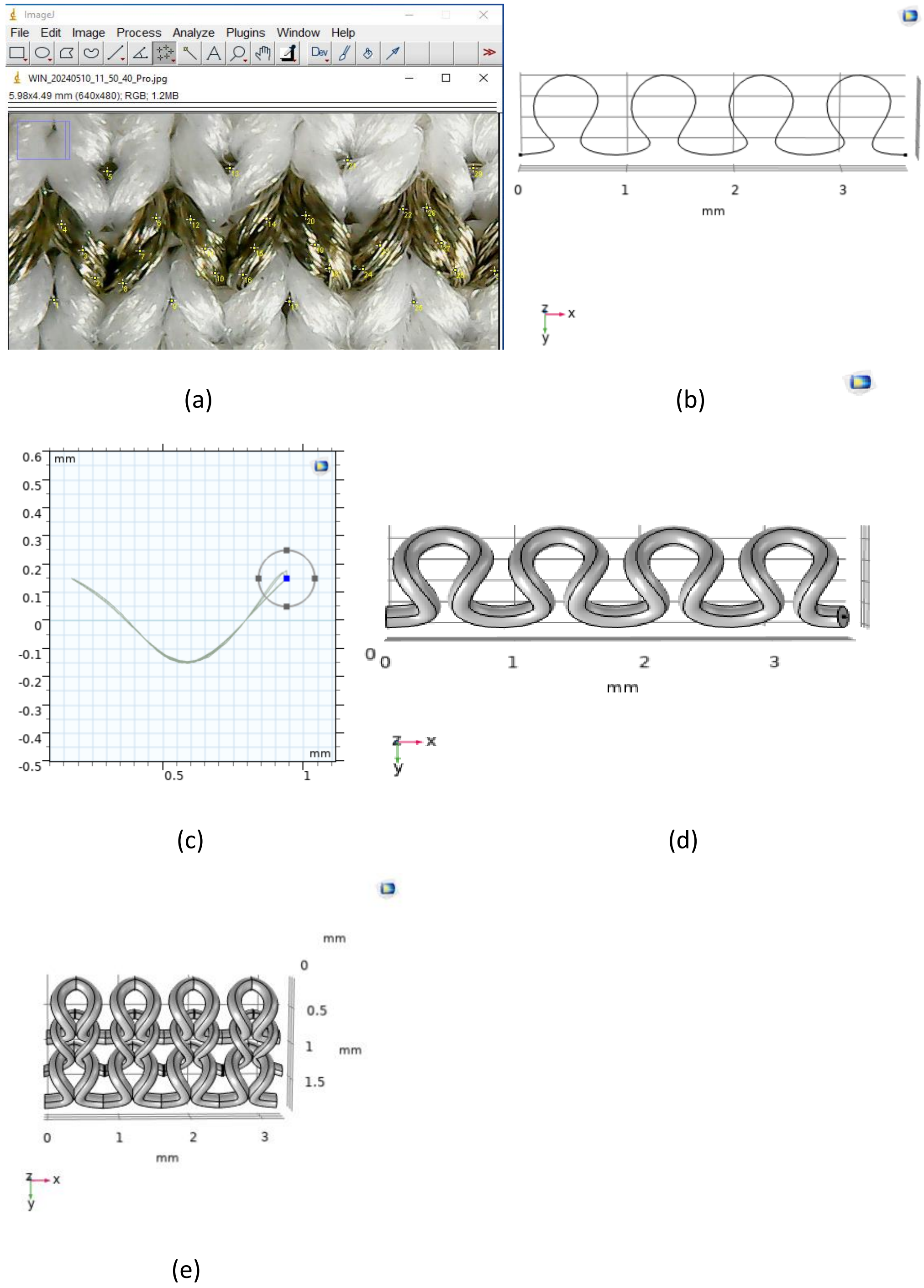
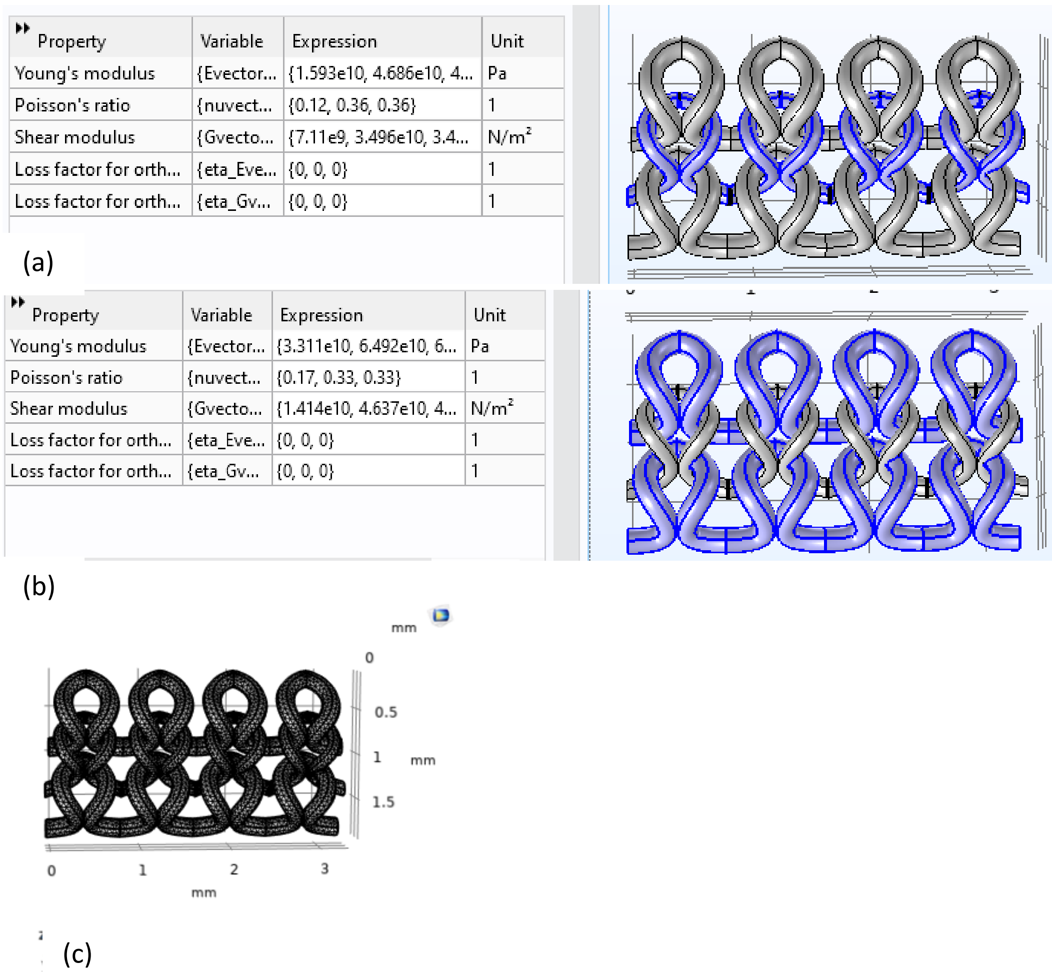


(d)

a)High stitch setting sample showing loose structure and lower course/wales density, b) low stitch setting sample showing compact structure and high course/wales density, c) SJKSS before stretch (at normal condition), d) SJKSS after stretch



a)Finding interpolation points from multi-point option of captured image through Image J software, b)Generated curve of a knitted loop in COMSOL Multiphysics, c)View of a circle equivalent to radius of yarn, d)View of a sweeped knitted loop e)Finalized geometrical model of single jersey fabric



Property	Variable	Expression	Unit
Young's modulus	{Evector...	{1.593e10, 4.686e10, 4...	Pa
Poisson's ratio	{nuvect...	{0.12, 0.36, 0.36}	1
Shear modulus	{Gvecto...	{7.11e9, 3.496e10, 3.4...	N/m²
Loss factor for orth...	{eta_Eve...	{0, 0, 0}	1
Loss factor for orth...	{eta_Gv...	{0, 0, 0}	1

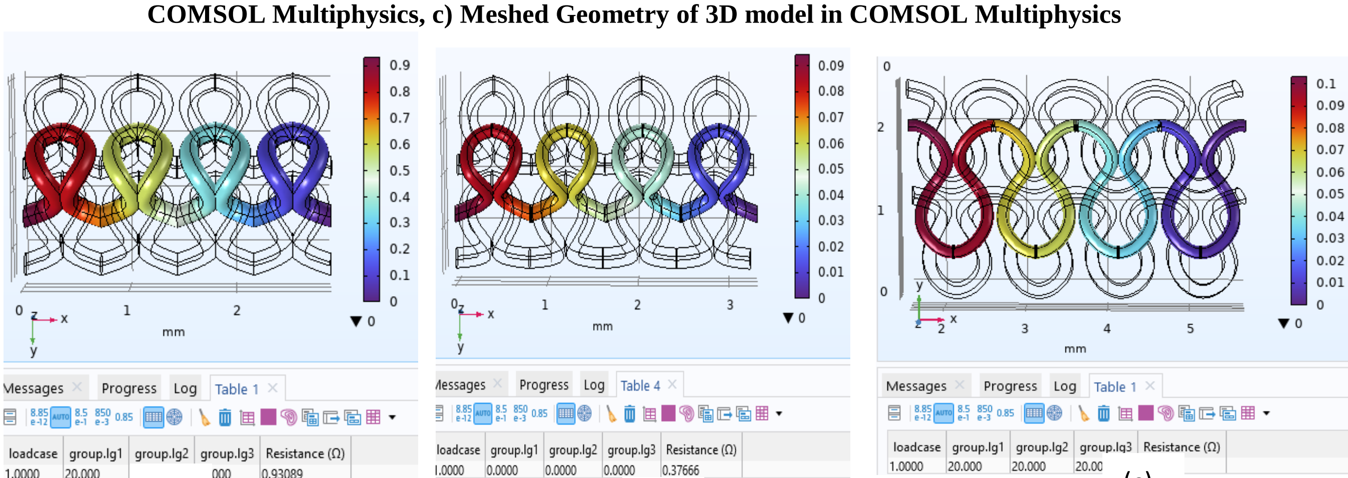
(a)

Property	Variable	Expression	Unit
Young's modulus	{Evector...	{3.311e10, 6.492e10, 6...	Pa
Poisson's ratio	{nuvect...	{0.17, 0.33, 0.33}	1
Shear modulus	{Gvecto...	{1.414e10, 4.637e10, 4...	N/m²
Loss factor for orth...	{eta_Eve...	{0, 0, 0}	1
Loss factor for orth...	{eta_Gv...	{0, 0, 0}	1

(b)

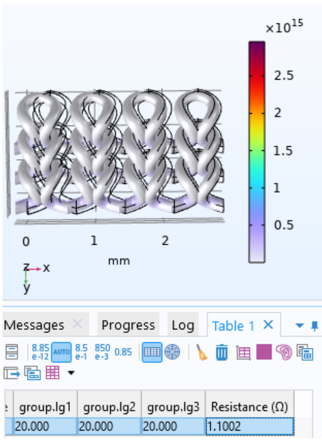
(c)

a) Material properties of conductive yarn in COMSOL Multiphysics, b) Material properties of base yarn in COMSOL Multiphysics, c) Meshed Geometry of 3D model in COMSOL Multiphysics

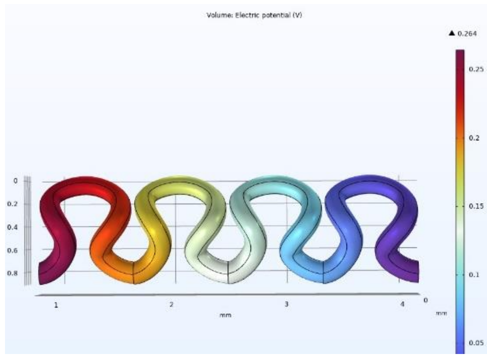


(a) (b) (c)

(a) Initial resistance of sample B20C20 (b) Initial resistance of sample B20C230 (c) Initial resistance of sample B35C50



(a)



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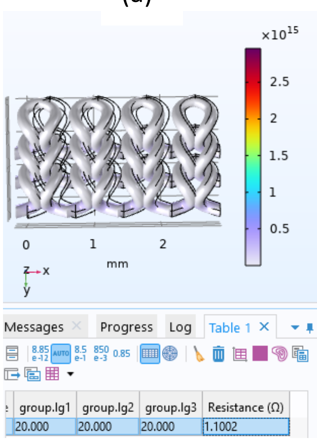

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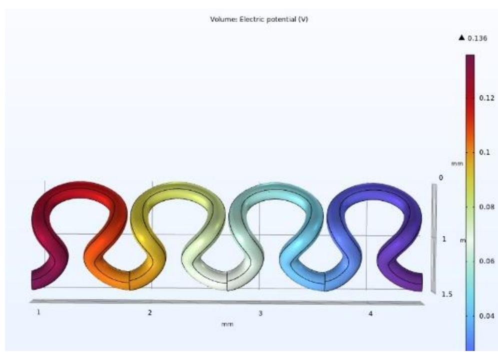

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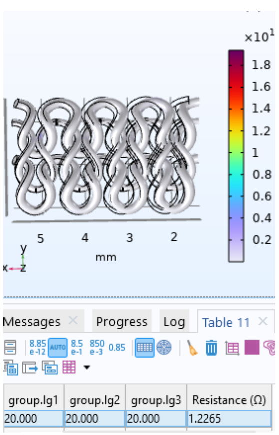

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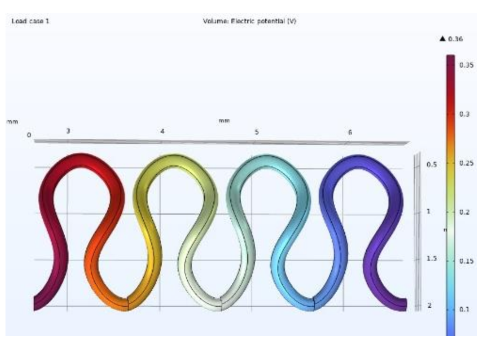

(f)

a)Animated view of sample B20C20 at 20% strain (b) Current flow in conductive part of sample B20C20 at 20% strain (c) Animated view of sample B20C30 at 20% strain (d) Current flow in conductive part of sample B20C30 at 20% strain (e) Animated view of sample B35C50 at 20% strain (f) Current flow in conductive part of sample B35C50 at 20% strain