Characterization of Mechanical Properties of Rubber Bands in Various Configurations

Authored by Lucy Lin
Supervised by Dr. Philip Cardiff

INTRODUCTION

Rubber bands, known for their remarkable elasticity, are used in various applications from simple household tasks to complex engineering uses. This study draws inspiration from the Rainbow Loom bands, where basic series patterns exhibit high elasticity while advanced patterns like fish-tails or hexa-fish are sturdier and less stretchable due to their configurations. The motivation for this project is to understand the mechanical properties of rubber bands in different configurations – series, parallel, and hybrid – using a Material Testing System (MTS) machine. The goal is to analyze the force-displacement behavior and compare the mechanical properties of these configurations, contributing to the design and optimization of elastic components in engineering applications.

Approach

The research investigates the properties of rubber bands in various configurations using an MTS machine, focusing on the force-displacement relationship during deformations.

METHODOLOGY

Tools and Materials

- Rubber Bands: Consistent, non-pre-stretched for repeatability.
- MTS Machine: Applied controlled forces and measured deformations.
- Python: Used for data cleaning, formatting, and visualization with Matplotlib.

Experimental Design

- Configurations
  - Series: Rubber bands connected in series by knotting -> example below [1].
  - Parallel: Rubber bands arranged in parallel for uniform load distribution.
  - Hybrid: Combinations of series and parallel arrangements.
- MTS Machine Setup: Ensured rubber bands were straightened on hooks without pre-stretching. The machine lifted the top hook, stretching the rubber band configurations while the bottom hook remained fixed.

Data Collection

- Initial Tests
  - 3 parallel rubber bands at 20 inches/minute.
  - 3 rubber bands in series at 10 inches/minute.
- Subsequent Tests
  - Mixed configuration of 2 series of 2 parallel bands.
  - Mixed configuration of 2 series of 3 parallel bands.
  - 2 parallel rubber bands at 10 inches/minutes.

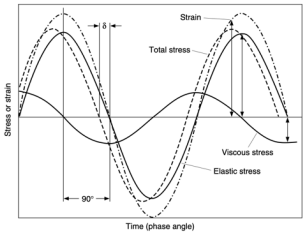
Data Processing and Analysis

- Data Cleaning and Formatting of .csv file data in Python – assigned column names and converted columns to numeric types.
- Data Visualization – plotted data to visualize relationships for configurations.

DISCUSSION

The results matched the expected mechanical properties of rubber bands in different configurations. Parallel configurations showed higher stiffness and steady load increases, while series configurations demonstrated lower stiffness and gradual load increases, allowing for more flexibility.

Mixed configurations exhibited complex behaviors with significant load fluctuations, influenced by the connections and interactions of the rubber bands. Initial decreases in load were observed due to slack or knots being taken up, emphasizing the need for consistent and secure connections.



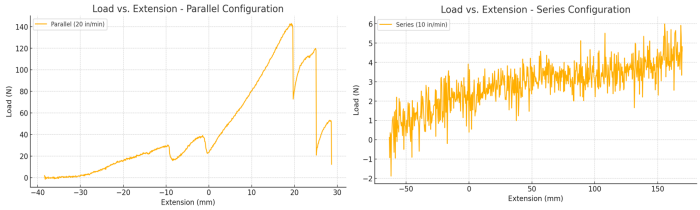
The figure above shows how, with rubber material, the total stress is composed of elastic and viscous components, with a phase lag between the applied strain and the resultant stress [2]. This relationship helps explain the initial fluctuations and complex load behaviors observed in our mixed configurations, indicating that the mechanical response is influenced not only by the properties of the rubber bands but also by their interactions and connections.

Future work should include multiple trials, standardized connections, and comprehensive strain rate analysis to enhance reliability and provide further insights into the mechanical behavior of rubber bands. It may be interesting as well to ignore different combinations.

RESULTS

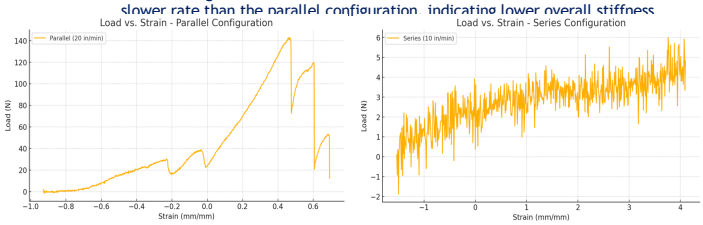
Load vs. Extension

- Parallel Configuration (3 parallel rubber bands at 20 inches per minute)
  - A gradual increase in load with extension. Initial fluctuations indicate adjustments as the rubber bands start to stretch, stabilizing as extension increases. The combined stiffness resists deformation.
- Series Configuration (3 rubber bands in series at 10 inches per minute)
  - An initial decrease in load due to slack or knots being taken up, followed by a gradual increase. The load increases at a slower rate compared to the parallel configuration, indicating more compliance.



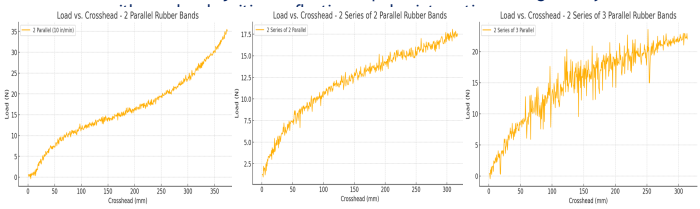
Load vs. Strain

- Parallel Configuration (3 parallel rubber bands at 20 inches per minute)
  - A linear increase in load with strain like the Load vs. Extension graph. Initial fluctuations indicate adjustment periods, stabilizing with a steady load increase.
- Series Configuration (3 rubber bands in series at 10 inches per minute)
  - An increasing trend with initial fluctuations. The load increases with strain at a slower rate than the parallel configuration, indicating lower overall stiffness



Load vs. Crosshead

- 2 Parallel Rubber Bands at 10 inches per minute
  - A gradual increase in load with crosshead position, typical of parallel configurations. Initial fluctuations indicate settling or minor adjustments.
- 2 Series of 2 Parallel Rubber Bands (4 rubber bands in total)
  - Noticeable fluctuations in load due to complex interactions between series and parallel configurations. The load generally increases with crosshead position, with varying rates due to knots and interactions.
- 2 Series of 3 Parallel Rubber Bands (6 rubber bands in total)
  - Pronounced fluctuations, with an initial decrease in load followed by an increase. This indicates adjustments and the impact of knots. The load generally increases



Interpretation and Comparison of Results

- Parallel Configuration
  - Higher stiffness due to combined resistance.
  - Steady increase in load with extension and strain.
  - Suitable for high load-bearing capacity with limited deformation.
- Series Configuration
  - Lower overall stiffness with individual stretching.
  - Gradual increase in load with extension and strain.
  - Suitable for greater flexibility and larger deformations.
- Mixed Configurations
  - Complex interactions with fluctuating load behavior.
  - Moderate to high flexibility, balancing load bearing and flexibility

ACKNOWLEDGMENTS

I would like to extend my sincere gratitude to Dr. Philip Cardiff for his invaluable guidance and support throughout this project. Additionally, I thank Dr. Kevin Nolan for his exemplary management of this program.

BIBLIOGRAPHY

[1] Laird, G. (n.d.). Exploratorium. Retrieved from https://www.exploratorium.edu/sites/default/files/snacks/BottleRacer_DSC_5178_P640.jpg
[2] Schaefer, R. J. (n.d.). Chapter 33 Mechanical Properties of Rubber. In Harris' Shock and Vibration Handbook (Fifth, p. 33.1-33.18). essay. Retrieved from https://www.mtec.or.th/wp-content/uploads/2018/04/mechanical-properties_rubber.pdf

University College Dublin
University of Pennsylvania

CONTACT: LucyLin@seas.upenn.edu
https://www.linkedin.com/in/LucyyLinn/