

Explaining Fracture from Theory to Experiment to Applications

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Abstract—The concept of fracture connects fundamental ideas in physics to important physical and biological phenomena observed in everyday life. Representing the point at which a material can no longer withstand additional strain, fracture marks the transition from deformation to complete structural failure. The fracture of material can be divided into three main categories: Brittle, Ductile, and Elastomer. To understand how a fracture takes place, an experiment was performed using a rubber band. This experiment shows how an elastic material follows the concept of Elasticity-Deformation in terms of stress-strain, and shows all stages a rubber band can go through from the elastic stage to the plastic stage and then to Fracture. Understanding each stage of deformation can bring better ways of protecting a fracture to occur and to modify materials for real-world applications. The types of materials used in real-world applications, from engineering to Medical to everyday life, can be modified if they are fused with combinations of two types of materials, for example, rubbery brittle, or rubbery ductile. The Experimental data clearly showed that it followed the theory and concepts of Fracture that can be used as a tool of modification in materials for engineering and biological contexts.

Keywords— Fracture, Hooke’s Law, Force, Extension, Stress, Strain, Elasticity, Deformation, Brittle, Ductile, Elastomer, Rubber band, yield point, Young’s modulus, Ultimate strength, Elastic energy, Plastic energy, Fracture Energy, Work, Spring Constant, Physics.

I. INTRODUCTION

Fracture is a fundamental concept in physics that governs the infrastructure of the world around us, describing the point at which a material fails under stress and separates into two or more pieces. Although a fracture is often not noticeable until the material separates, it is the predictable result of a progressive relationship between stress and strain, where stress is defined as force applied per unit area and strain as the ratio of deformation relative to the original length of a material. Before a fracture occurs, materials typically undergo stages of deformation that can be understood through the principles of elasticity, which describe how materials respond to applied forces and whether they return to their original shape.

This relationship is commonly represented through a stress-strain curve, shown in Figure 1, which illustrates how materials respond under increasing load. On this curve, the initial region from point A to B represents linear elastic behavior where Hooke’s Law applies, and deformation is fully reversible. As the curve begins to deviate from linearity beyond point B, the material approaches the yield point, marking the transition from elastic to plastic behavior. The

material retains elastic properties up to point C; beyond this point, small increases in stress lead to disproportionately large increases in strain, indicating the onset of permanent deformation. Eventually, the material reaches point D, the fracture point, where the internal structure can no longer sustain the applied force, and complete failure occurs.

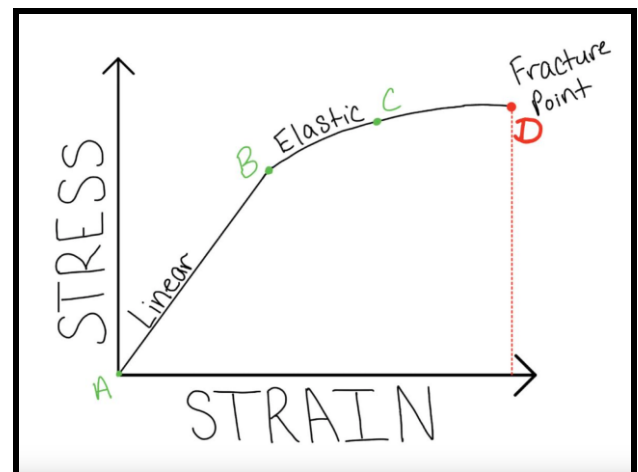


Figure 1: Physics of Fracture showing the concept behind it.

The material's structure determines the precise deformative response [1]: ductile materials experience considerable plastic deformation before breaking, whereas brittle materials break quickly after only a small amount of deformation. Elastomers, such as rubber, exhibit a different behavior characterized by large elastic deformation before returning to their original shape, allowing them to absorb and release energy efficiently. These distinctions highlight how internal structure governs material response under stress, with the respective fracture points indicated by the red dot at the end of each curve, shown in Figure 2. This demonstrates theoretical understanding that ductile and elastomeric materials assume more strain than can occur, but withstand less stress before resulting in fracture for three main types of materials: Brittle, Ductile, and Elastomer.

Beyond material classification, these principles extend to how forces act in real systems. Physics provides a framework for understanding not only material failure but also everyday phenomena, where stress has direct implications on biological systems as well. For example, how forces are applied to the human body influence strain and potential injury, like how landing awkwardly can result in a bone fracture, demonstrating how mechanical principles directly affect bone stability [2].

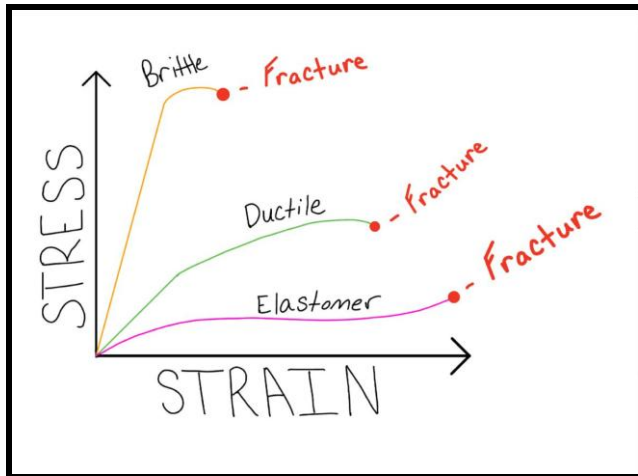


Figure 2: Stress-Strain curve showing three main categories of material in fracture: Brittle, Ductile, and Elastomeric materials.

In addition to mechanical forces, material behavior is influenced by external conditions such as temperature, where changes can alter internal energy and structure, affecting stability and response to stress as well [3]. It is therefore necessary to consider that stress and strain may not be immediately clear to the eye, but the underlying principles can still be occurring due to the environment. The next section connects these ideas and establishes fracture as a concept that bridges theoretical physics and real-world behavior across disciplines.

Importance of Fracture in Applications:

These fundamental principles of fracture extend directly into infrastructure and health-related applications, where understanding how materials fail is critical for safety and performance. Materials are commonly categorized as brittle, ductile, or elastomeric based on their stress-strain behavior, as seen in Figure 2. Brittle materials, including glass, ceramics, and bricks, fracture suddenly with minimal deformation, making them useful in applications requiring rigidity but vulnerable to sudden failure. Ductile materials such as steel and iron undergo significant plastic deformation before fracture, allowing them to absorb energy and provide a warning before failure, which is essential in structural design. Elastomers, including rubber, exhibit large elastic deformation and high energy absorption, making them valuable in applications requiring flexibility and resilience.

These differences are illustrated in comparative stress-strain curves, where materials like steel display a steep slope and a clearly defined yield point, while materials such as concrete exhibit a more gradual response, shown in Figure 3. The yield point represents the stress at which a material transitions from elastic to plastic deformation, meaning it will not return to its original shape after the load is removed. This property is critical in design as these metrics are selected to ensure that deformation occurs in a controlled manner to prevent catastrophic fracture. Understanding that, for instance, specific steel grades have different inherent characteristics and can be chosen to balance strength and flexibility, highlights the ability to choose materials that best support a given design,

and real-world material design reflects advancements in combining these properties.

While concrete is traditionally brittle, it can be modified into more ductile forms through innovations such as rubberized concrete, where recycled rubber particles replace portions of natural material. This modification improves ductility and impact resistance, making the material more suitable for applications involving dynamic loading, while also contributing to environmental sustainability through recycling [4]. Using this understanding may help not only in a construction setting but also in biomedical applications, where materials must withstand repeated mechanical loading while maintaining structural integrity. These applications demonstrate that fracture is not merely a theoretical concept but a critical factor in advancement in many sectors, where an understanding allows for the development of systems that can be resilient and efficient.

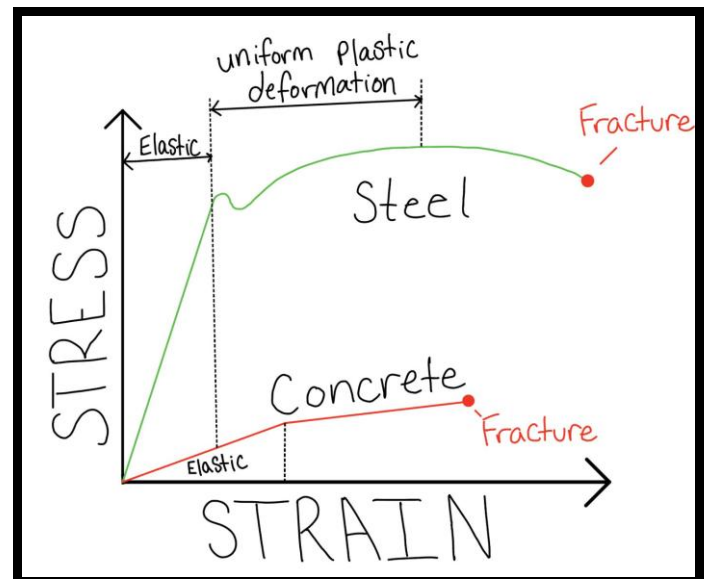


Figure 3: Steel and Concrete stress-strain relationships showing how Steel can be stronger than Concrete.

Recent developments in elastomers that exhibit stress-induced strengthening suggest that materials can be designed to not only withstand deformation but also improve their mechanical performance over time, which is particularly useful for applications such as prosthetics and soft tissue supports [5]. Even further, biological tissues are another point of interest in this focus. For example, the heart and lungs undergo repeated cycles of elastic deformation, stretching, and recoiling to pump blood and facilitate breathing. Similarly, bones exhibit elastic behavior under normal physiological loads, undergoing small, reversible deformation during activities such as walking or jumping. However, when forces exceed the elastic limit, microfractures can develop within the bone structure. With continued or excessive loading, these microfractures can accumulate and lead to a complete fracture. This behavior is consistent with the principles of stress-strain relationships and fracture mechanics, which describe how materials absorb and dissipate energy under load [6].

In medicine, similar principles help explain how bones fracture under excessive stress, how tendons and ligaments stretch and may fail when strained beyond their elastic limit, and how orthopedic implants must be designed to withstand repeated mechanical forces within the body. For example, tendons exhibit non-linear stress-strain behavior and can undergo permanent deformation or rupture when subjected to excessive loading, similar to the behavior observed in the rubber band [7]. Additionally, biomedical implants such as joint replacements and fixation devices are engineered with specific mechanical properties to balance strength and flexibility, reducing the risk of fracture or fatigue failure under cyclic physiological loads. By examining a simple rubber band under increasing load, this experiment provides insight into the fundamental physics behind fracture and material failure in both biological tissues and engineered medical systems.

To further investigate these concepts experimentally, a rubber band was used as a model system to analyze elasticity and fracture behavior under increasing load. By progressively adding weight and measuring the change in length, it becomes possible to visualize how materials transition from elastic deformation, where they return to their original shape, to plastic deformation, where permanent damage occurs, and ultimately to fracture. Theories involved in these experiments are shown below in the theory section. The data and results section shows visualizations of the experimental data, which were used to determine the Spring Constant and Young’s modulus. Additional calculations were performed to assess the work done and the fracture energy. These theories are expanded on in the section below. The goal is to evaluate how well a rubber band follows the principles of fracture and to assess how these observations can be adapted to real-world applications and potential future research.

Theory Involved in Elasticity and Fracture:

The deformation of elastic materials can be described by Hooke’s Law, Young’s modulus, and Elasticity - Deformation. Hooke’s Law states that the restoring force is proportional to the change in length (equation 1), while Young’s modulus relates stress to strain as a measure of material stiffness (equations 2 and 3). Young’s modulus can also be calculated by using the spring constant from Hooke’s Law (equation 4). Work was calculated using the integral form of the Work-Energy Theorem (equation 5). Griffith’s Theory for fracture mechanics was used to estimate fracture energy as the energy per unit area (equation 6). Lastly, the percent error formula was used to compare the difference between the calculated and slope-derived Young’s modulus values (equation 7).

$$F = -k \cdot \Delta L \tag{1}$$

$$F/A = Y \cdot (\Delta L/L) \tag{2}$$

$$Y = (F \cdot L)/(A \cdot \Delta L) \tag{3}$$

$$Y = k \cdot L/A \tag{4}$$

$$W = \int F \cdot \Delta L \tag{5}$$

$$G = W/A \tag{6}$$

$$(|Y_c - Y_s|/Y_c) \cdot 100 \tag{7}$$

Where F is the force (N), k is the spring constant (N/m), ΔL is the change in length (m), L is the original length

(m), A is the cross-sectional area (m²), Y is Young’s modulus (Pa), W is Work (J), G is Fracture Energy (J/m²), Y_c is the calculated Young’s modulus (Pa), and Y_s is the slope-derived Young’s modulus (Pa).

II. EXPERIMENTAL PROCEDURE

To investigate the relationship between applied force and deformation, a rubber band was suspended from a fixed apparatus and gradually loaded with increasing weights. First, the initial length of the rubber band was measured in centimeters before any force was applied. This served as the baseline measurement for calculating deformation. Next, small weights were progressively added to the rubber band. After each addition of mass, the new final length of the rubber band was measured. The difference between the final length and the original length represented the change in length (ΔL).

To ensure accurate analysis, measurements were converted into SI units. Mass values originally measured in grams were converted to kilograms, and the change in length measured in centimeters was converted into meters. The force applied to the rubber band was calculated by multiplying the mass (kg) by acceleration due to gravity (9.81 m/s²). **Figure 4** shows the experimental design from the start to the fracture that occurred after 3.2 kg of weight was applied to the rubber band.



Figure 4: Pictures of the Experimental setup of the experiment at the beginning (left), mid-point (center), and final fracture (right).

III. DATA AND RESULTS

The experimental data and results are displayed in this section to see whether the findings follow the theory of elasticity and fracture.

Table 1 shows the outcome of each trial, with ΔL calculated from subtracting the measured length from the original length, and Force calculated by multiplying the mass and acceleration due to gravity (9.81 m/s^2).

A scatter plot was generated from the collected data, and a best-fit line was added to visualize the relationship between force and change in length. In Figure 5 below, the green arrow represents Hooke's Law, the blue line shows the non-linear region beyond Hooke's Law, and the red star shows the fracture in the rubber band.

The first eight rows of data, which follow a linear path in accordance with Hooke's Law, were used to perform a linear fit analysis to find the slope. Figure 6 shows the best-fit line with a slope of 23.42 N/m , which represents the spring constant of the rubber band.

TABLE 1: This table shows the experimental data collected and converted into SI units.

Trial #	1	2	3	4	5	6	7	8
ΔL (m)	0.01	0.02	0.05	0.09	0.14	0.19	0.23	0.27
Force (N)	0.49	0.98	1.96	2.94	3.92	4.91	5.89	6.87
Trial #	9	10	11	12	13	14	15	16
ΔL (m)	0.29	0.31	0.33	0.35	0.36	0.37	0.39	0.42
Force (N)	7.85	8.83	9.81	11.77	13.73	15.70	17.66	19.62
Trial #	17	18	19	20	21	22	23	
ΔL (m)	0.42	0.43	0.44	0.45	0.46	0.46	0.47	
Force (N)	21.58	23.54	24.53	26.49	28.45	29.43	31.39	

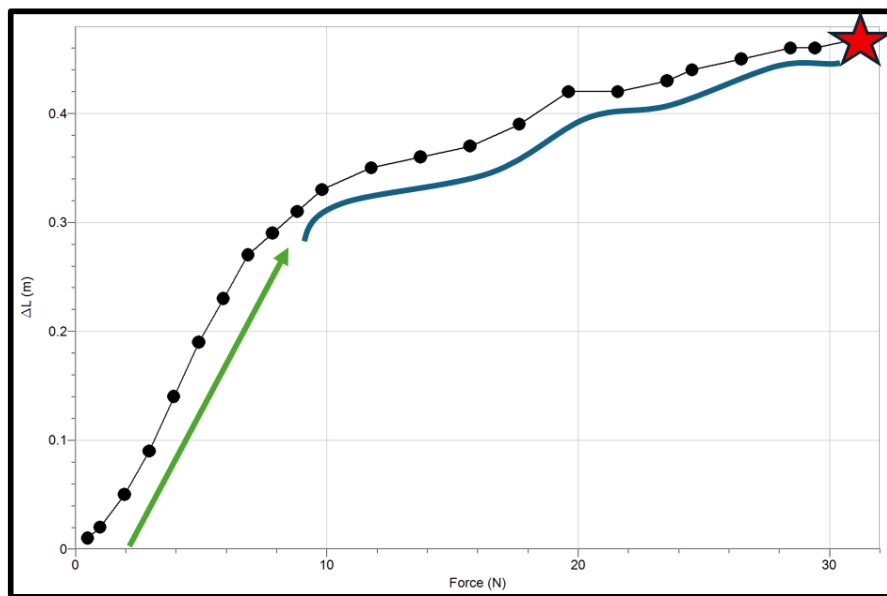


Figure 5: Force vs. Extension graph showing linear (Hooke's Law) and non-linear regions, with Fracture point indicated by a Red Star.

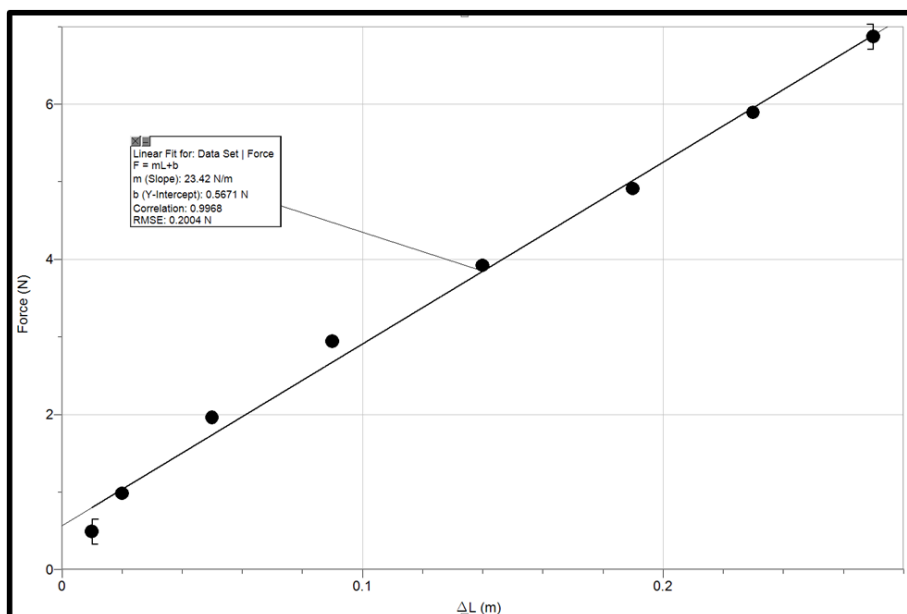


Figure 6: A linear fit analysis was performed to find the spring constant of the rubber band.

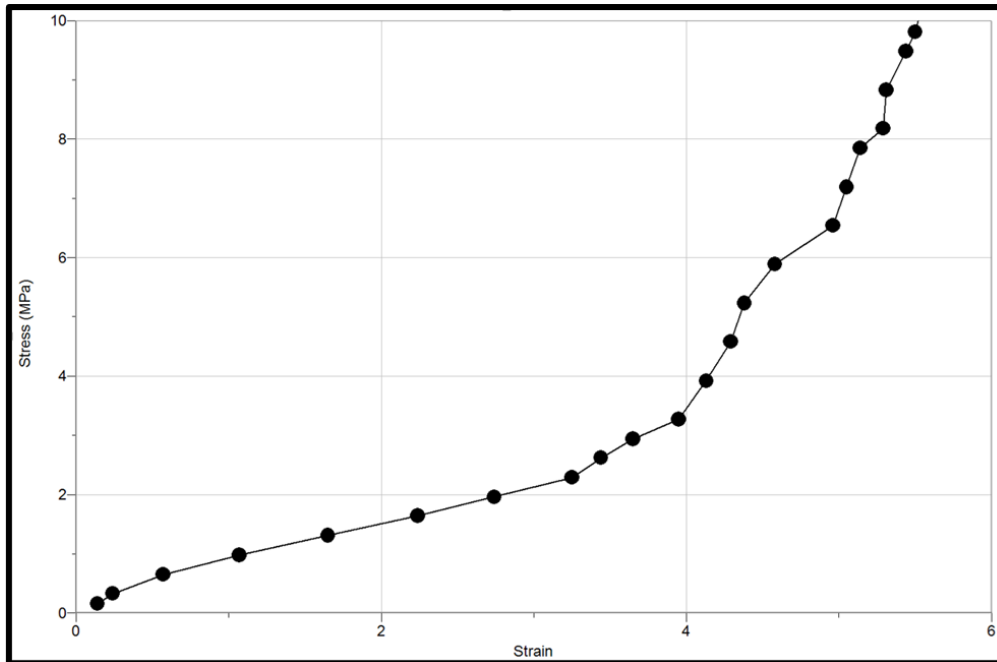


Figure 7: A scatter plot of stress vs strain of the rubber band.

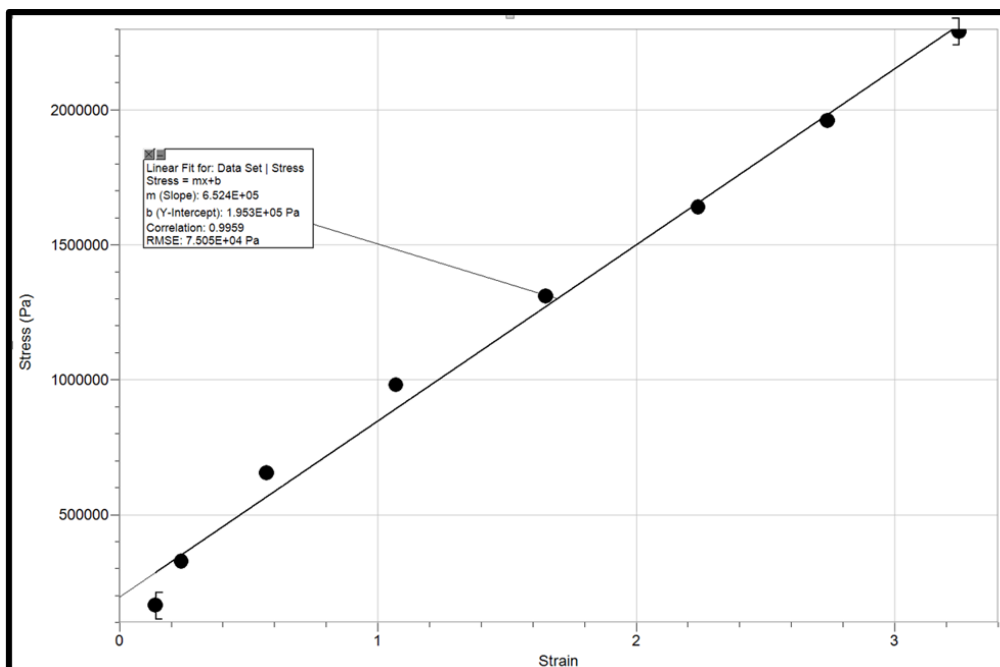


Figure 8: A linear fit analysis was performed to find Young's modulus for the rubber band.

The dimensions of the rubber band were measured and converted into SI units, which resulted in an area of $3.0 \cdot 10^{-6} \text{ m}^2$. This data was used to plot stress (F/A) over strain ($\Delta L/L$), shown in Figure 7.

Next, a linear analysis was done on the first eight rows of data using stress vs strain. From Figure 8 below, the slope was used to find Young's modulus as $6.524 \cdot 10^5 \text{ Pa}$.

Figure 9 shows the work done on the rubber band, which is the integral of the force vs extension curve. After converting into SI units, the result was 4.196 J. Work was used to calculate the fracture energy (G) by using equation 6 from the

theory section. The result was $1.399 \cdot 10^6 \text{ J/m}^2$, which indicates the amount of energy per unit area required to deform the material to the point of fracture.

Data Interpretation:

The linear relationships observed in the results confirm that the rubber band follows Hooke's Law within the initial region of deformation. In this region, force and extension are directly proportional, indicating elastic behavior in which the material returns to its original length once the applied force is removed.

As the applied force increases, the data begins to deviate from linearity, marking the limit of elastic behavior and the onset of plastic deformation. In this region, additional strain results in permanent structural changes, and the material no longer fully recovers its original shape. The final data point

represents the fracture point, corresponding to the maximum stress the material can withstand before failure. This behavior is consistent with stress-strain theory, where fracture occurs after significant deformation beyond the elastic limit.

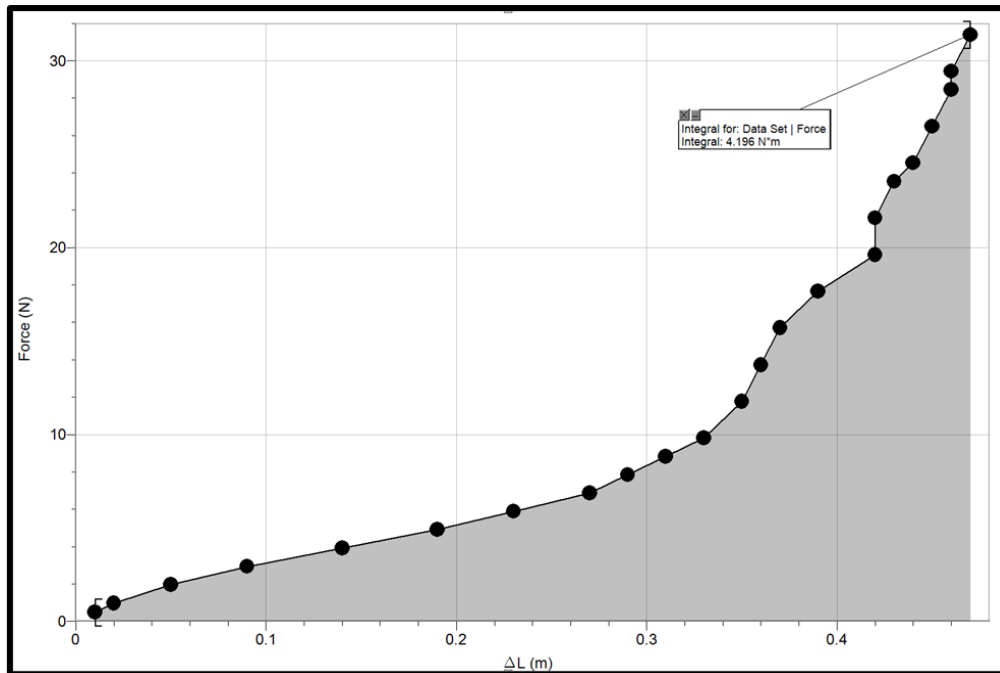


Figure 9: The area of Force (N) · ΔL (m) was calculated to find Work done (J) by the rubber band.

To further quantify the material’s mechanical properties, the spring constant (23.42 N/m) was used to calculate Young’s modulus (Y_c) using Equation 4. This value was compared to the slope-derived Young’s modulus (Y_s), and the percent error was found using Equation 7. The details of the percent error analysis are shown in Table 2 below.

TABLE 2: Percent error analysis of Young’s modulus for the rubber band.

Y_s	$6.524 \cdot 10^5$ Pa
Y_c	$6.558 \cdot 10^5$ Pa
% error	0.52 %

The percent error difference was 0.52%, indicating strong agreement between the two methods. This suggests that both the direct stress-strain approach and the calculation using the spring constant are consistent with theoretical expectations.

IV. DISCUSSION

The results of the experiment with the rubber band provide clear evidence of how an elastomer transitions from elastic to plastic deformation and ultimately fractures under increasing load. To better understand fracture, it is important to examine the stages of deformation the rubber band undergoes during the experiment, from its initial unstretched state through increasing deformation and ultimately to fracture, as illustrated in Figure 1 from the introduction.

The results of this experiment show that the elastomer followed Hooke’s Law within the initial region, as demonstrated by the linear relationship between force and

extension. As shown in Figure 10, this portion of the curve represents the elastic region (shown in blue), where the energy applied to stretch the material is stored as elastic potential energy and can be fully recovered once the force is removed.

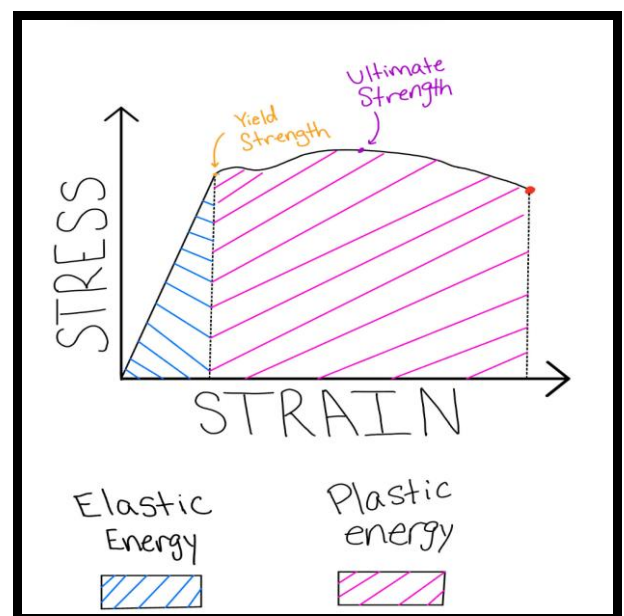


Figure 10: Plastic and Elastic energy of materials.

While the area under the linear portion of the curve represents elastic energy, the area under the non-linear curve represents

the plastic region (shown in pink), where increased energy absorption leads to permanent structural changes. However, at this point, the energy cannot be fully recovered as in the elastic region.

In line with the stress-strain theory presented in the introduction, the ultimate breaking point strengthens the notion that materials fail when they surpass their mechanical boundaries. As the material approaches this point, accumulated deformation and internal structural changes reduce its ability to withstand additional stress. This progression reflects the increasing irreversible deformation, where energy is no longer stored elastically but instead contributes to material failure. Ultimately, the fracture point represents the culmination of these processes, marking the transition from deformation to complete structural breakdown.

Following the concept shown in Figure 10, a similar graph was plotted with the experimental results of the rubber band in Figure 11 to compare the rubber band's results with the conceptual graphs. In Figure 11, the areas of each region were calculated to determine the elastic energy and plastic energy, which were $4.119 \cdot 10^6$ J and $1.226 \cdot 10^7$ J, respectively. The significantly larger plastic energy indicates that, beyond the elastic limit, a greater portion of the applied energy is used to permanently deform the rubber band and contribute to the fracture rather than being stored elastically.

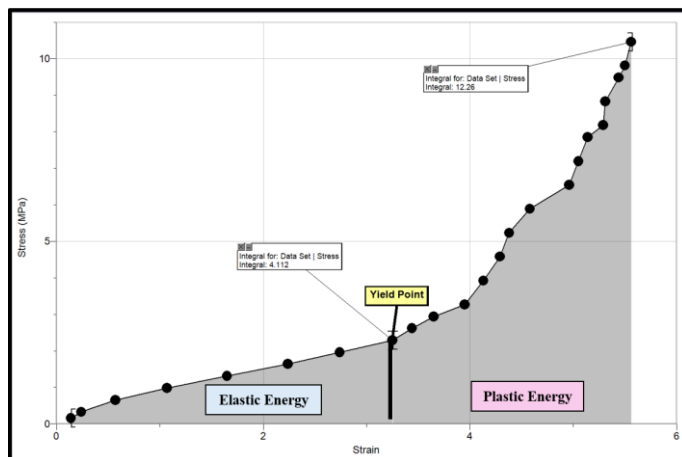


Figure 11: The area of the linear segment shows Elastic Energy (left) and the non-linear segment shows Plastic Energy (right).

The fracture energy is directly related to the total work done on the material, as it incorporates both elastic and plastic contributions to deformation. While elastic energy represents recoverable deformation and plastic energy represents irreversible deformation, their combined effect corresponds to the total energy absorbed before fracture. Using equation 6, the fracture energy was found to be $1.399 \cdot 10^6$ J/m².

The yield point marks the transition between elastic and plastic behavior, indicating the stress at which permanent deformation begins. In this experiment, the yield point was $3.249 \cdot 10^6$ Pa. This value corresponds to the point at which the material begins to absorb energy through irreversible deformation rather than storing it elastically, further supporting the observed increase in plastic energy as the material approaches fracture.

A comprehensive overview of the rubber band's mechanical behavior under increasing load is summarized in Table 3.

TABLE 3: Summary table of calculations of the rubber band experiment.

Spring Constant	23.42 N/m
Young's Modulus	$6.524 \cdot 10^5$ Pa
Work	4.196 J
Area	$3.0 \cdot 10^{-6}$ m ²
Fracture Energy	$1.399 \cdot 10^6$ J/m ²
Elastic Energy	$4.114 \cdot 10^6$ J
Plastic Energy	$1.226 \cdot 10^7$ J
Yield Point	$3.249 \cdot 10^6$ Pa

The work calculated from the force–extension curve represents the total energy absorbed by the material during deformation. This is reflected in the relative magnitudes of the elastic and plastic energy components, where the significantly larger plastic energy indicates that irreversible deformation dominates as the material approaches fracture. The calculated fracture energy represents the total energy per unit area required to bring the material to failure. As it is derived from the total work, it incorporates both elastic and plastic contributions to deformation. Together, these values illustrate how energy is absorbed and redistributed within the material as it transitions from elastic behavior to plastic deformation and ultimately to fracture.

In comparison to other common materials, the elastomer tested in this experiment exhibits behavior that is distinct from both ductile and brittle materials. It is understood that there are different theoretical yield strengths that are generally accepted, as steel is a ductile material with a typical yield strength ranging from about 250 to over 1,300 MPa, meaning it can undergo significant deformation before failure. In contrast, concrete is a brittle material with a compressive strength typically between 30 and 80 MPa, and it fails abruptly with little to no plastic deformation. Rubber, however, is highly elastic and capable of undergoing large deformations without a well-defined yield point, which aligns with the behavior observed in this experiment [8].

TABLE 4: Characteristics and Yield Ranges of Common Materials.

Material Type	Material Example	Characteristics	Yield Point Range
Brittle	Brick	Fails super abruptly	20 to 40 MPa
Brittle	Concrete	Fails abruptly	30 to 80 MPa
Ductile	Iron	Deforms then fails	100 to 800 MPa
Ductile	Steel	Deforms then fails	250 to 1,300 MPa
Elastomer	Rubberband	Stretches high, then fails	2.0 to 4.0 MPa
Elastomer	Rubber	Highly flexible	Unlimited or N/A

Table 4 offers such comparisons in these materials, which all bears thought when thinking of the characteristics needed for different needs. Unlike steel or concrete, the elastomer stores a large amount of energy through stretching and releases it efficiently, demonstrating its ability to sustain significant strain while remaining within or near the elastic region for much of the deformation process. Alternatively, this table

offers how ductile and brittle materials differ in terms of their yield points as well. Brittle materials, which fail after only slight strain, have yield point ranges considerably lower than ductile materials such as steel. This comparison highlights how different materials respond to stress and reinforces the importance of selecting materials based on their mechanical properties for specific applications.

Overall, this experiment supports theoretical models of material deformation and fracture while demonstrating how elastomers respond to increasing stress. The measured yield point of the rubber band was $3.249 \cdot 10^6$ Pa, which follows the same range as reported in Table 4 for elastomeric materials. The calculated values for the spring constant and Young's modulus were consistent across methods, with a low percent error of 0.52%, suggesting reliable results. Any discrepancies may be attributed to measurement uncertainty and the inherently nonlinear behavior of elastomers.

These findings are directly relevant to real-world situations where materials experience repeated or increasing mechanical loading, as shown in Figure 12. The ability to store and release energy is not limited to synthetic materials like rubber bands but is also observed in biological systems. For example, tendons may stretch and hold energy when placed under a load, which is later released to support movement and reduce metabolic energy expenditure [9]. Experimental studies on human Achilles tendons explore this idea, showing the intricacy of theoretical understanding to practice. It has been found that Achilles tendons exhibit complex strain behavior under increasing load, with localized deformation increasing significantly just before rupture, reinforcing the idea that biological tissues follow similar stress-strain and failure patterns as the elastomer observed in this experiment [10]. This behavior reflects deformation within the elastic limit, where no permanent structural change occurs.

In structures such as sidewalks, buildings, and railroad tracks, stress accumulates over time due to environmental forces and repeated use. While these systems are designed to remain within elastic limits, exceeding these limits leads to permanent deformation, such as cracking in concrete or buckling in rails. The intentional gaps in railroad tracks specifically reflect the same principle observed in this experiment, with the intentional controlled deformation to prevent stress buildup that could otherwise lead to fracture. This mirrors the behavior of the elastomer in this study, where continued loading eventually caused deviation from elastic behavior and ultimate failure, showing how the behavior of all materials in a stress-strain context must be considered in the functioning of everyday life.

The experiment of the rubber band exhibited both elastic and plastic deformation, with a clear transition from a linear to a non-linear stress-strain relationship as the applied force increased. A fracture in the rubber band can be seen as an example of an elastomer with a fracture. Figure 13 shows the rubber band before and after fracture, illustrating the physical changes that occurred as a result of the applied stress.



Figure 12: Pictures observed in buildings, walkways, and railways as an application of Fracture in Brittle (brick and concrete) and Ductile (steel and iron).

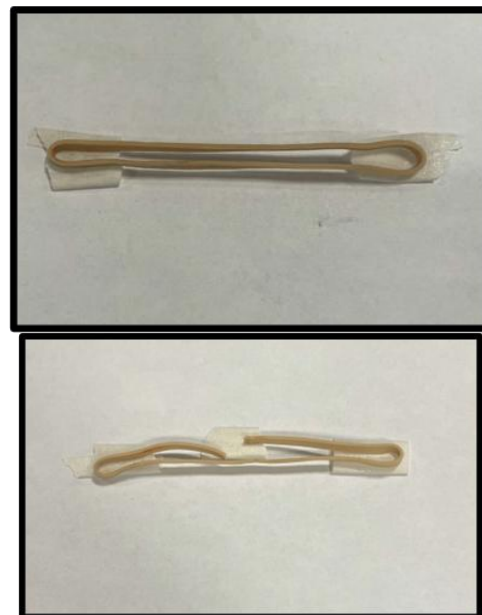


Figure 13: Pictures of the Rubber band used for the experiment show its original length before any force is applied (left), and when a fracture has occurred (right).

After explaining Fracture using concepts of Physics and Theories mentioned above, it is clearly seen that experiments performed with the rubber band follow all concepts and showed that the rubber band is a good example of showing high elasticity and extension under moderate type of forces. Based on Table 4, it can be seen that brittle material cannot withstand more stress and extends less before reaching fracture. Whereas Ductile can bear much higher stress and strain and extend more. Elastomers are materials that can extend tremendously without showing a definite yield point.

Scientists and industrialists are doing further research to modify materials for applications so that Fracture can be pushed further than expected. Brittle and Ductile materials can be modified for engineering, technology, medical, and daily use applications, such as creating a rubbery concrete, rubber brick, or using rubbery features in ductile. [11-12]

V. CONCLUSION

The physics observed in this experiment closely mirrors how materials deform under force in many real-world applications. Biological tissues, for example, exhibit similar elastic and plastic behavior under physiological loads. Bones undergo small, reversible deformation under normal conditions but can develop microfractures and ultimately fail when subjected to excessive stress, while tendons and ligaments exhibit non-linear behavior and may rupture when strained beyond their elastic limits. These same principles are also critical in biomedical engineering, where implants and fixation devices must be designed to withstand repeated mechanical forces while minimizing the risk of fracture or fatigue failure.

Beyond biological systems, these concepts are equally important in engineered materials, from designing vehicles that absorb energy during collisions to developing durable materials that resist fracture. The ability to understand and quantify stress-strain relationships and energy absorption allows engineers to optimize materials for both strength and flexibility in a wide range of applications. These applications are critical when engineered materials are designed to optimize performance and safety.

Ultimately, the experiment of the rubber band demonstrates how fundamental mechanical concepts such as elasticity, energy absorption, and fracture can be used to predict material behavior under increasing stress. By quantifying these properties, scientists and engineers are better equipped to design safer structures, improve biomedical devices, and better understand the mechanisms that lead to material failure in both natural and engineered systems.

Fun Part: A poem on Fracture:

Fountain is running, creating coolness.

Rose is blooming, bringing fragrance.

Ants are walking, showing calmness.

Cows are mooing, bringing happiness.

Thunder came all of a sudden.

Under the earth, stress is sudden

Ripped tectonic with rupture.

Earthquake brought a big **F**racture!

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