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Development of Strain Measurement System for Detecting Rubber Elasticity for Structural Health Monitoring Applications

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ABSTRACT

This paper investigates the correlation between rubber elasticity and strain measurement, aiming to advance the understanding and utilization of natural rubber in Structural Health Monitoring (SHM). Natural rubber, derived from latex found in rubber-producing plants, possesses exceptional elasticity and resilience, allowing strain measurement applications. This study employs strain gauge sensors and a Wheatstone bridge configuration to accurately assess the strain experienced by various rubber samples which are Rubber 1, Rubber 2, and Rubber 3 under different loading conditions. The differences between all three rubber samples are in the content of carbon black of size in the rubber. Rubber 1 contains carbon black of size N330 (60%), Rubber 2 contains carbon black of size N550 (60%), and Rubber 3 does not contain any carbon black. Through experimental analysis, it is demonstrated that as the applied load increases, the measured strain detected by the strain gauge rises, leading to an increase in the bridge output voltage. The proposed method, Rubber 2 is increased 11.94% in elasticity compared to Rubber 1 and Rubber 3 increased 15.82% in elasticity compared to Rubber 1. Among the tested rubber samples, Rubber 3 with higher elasticity exhibits a more significant increase in output voltage, indicating a stronger response to applied stress. The proposed strain measurement system effectively captures rubber elasticity, providing valuable insights into the mechanical properties of rubber components. Furthermore, this research aligns with Sustainable Development Goals (SDG), particularly SDG 12: Responsible Consumption and Production, by leveraging Malaysia's abundant natural rubber resources for innovative applications in structural health monitoring. Overall, this study contributes to the advancement of SHM techniques and the sustainable utilization of natural resources, with potential implications for various industries, including civil engineering and material science.

Keywords: Elasticity; strain measurement; natural rubber; structural health monitoring; strain gauge sensors; sustainable development

INTRODUCTION

Natural rubber (NR) is a natural polymer material biosynthesized by rubber-producing plants, such as Hevea brasiliensis, Taraxacum kok-saghyz and Parthenium argentatum (Guo et al. 2023). NR is an elastomer which is derived from the milky latex found in the sap of some plants. The pure form of natural rubber is the chemical polyisoprene (Al-Sabaeei et al. 2019). Polyisoprene can be produced synthetically since it has a double bond in each repeating unit. Due to the complex molecular chains of polyisoprene which form almost linear chains under loading and return to its original position when the load is removed, natural rubber (NR) has its physical properties which are typically elastic due to its high resilience and high stretch ratio. NR is well known as the naturally synthesized polymer which has superior elasticity in a wide range of temperatures (Sripornsawat et al. 2021). It is one of the most important biosynthesized polymers, and has excellent chemical and physical properties such as outstanding elasticity, flexibility, antivirus permeation, and good formability and biodegradability (Chen et al. 2023; Peng et al. 2010). So far, no synthetic materials can match natural rubber's unique combination of qualities, including its resilience, elasticity, abrasion, and impact resistance, efficient heat dissipation, and ability to remain flexible even in cold temperatures (Hakimi et al. 2021).

The need for chemical crosslinking among NR molecules is called vulcanization. Vulcanization is a process that makes rubber stronger, tougher, and more elastic by adding sulfur and heat (Coran, 2013). The sulfur atoms cross-link between the rubber molecules, creating a three-dimensional network that resists deformation and temperature changes. The NR turns to a non-biodegradable material that serves high mechanical and dynamical properties relating to high rolling and abrasion resistances. Vulcanized rubber is used for many products such as tires, hoses, belts, gaskets, seals, and rubber bands that require durability and flexibility. Vulcanization is a key innovation in the history of rubber as it enabled its widespread use in various industries and applications. As a derivative of natural rubber with the most abundant rubber resources, rubber is widespread used in the field across various industries and sectors, including civil infrastructure, aerospace, automotive and maritime (L. Huang et al. 2022; Umar et al. 2023; Y. Wang et al. 2023).

Rubber materials have been widely used in a variety of engineering applications such as rubber bearings due to their vibration damping and energy absorption qualities (Seesaard & Wongchoosuk, 2023). Taking advantage of rubber elasticity, the rubber material is seen to have the potential to be used in Structural Health Monitoring (SHM) due to its elasticity property that can be translated into strain. However, the ability to accurately measure the elasticity of rubber materials presents a significant challenge.

Recent advances in the development of dynamic sensors using rubber materials have shown significant promise, particularly in the field of flexible and wearable sensors. Rubber-based sensors are gaining attention due to their excellent flexibility, stretchability, and ability to conform to various surfaces, making them ideal for applications in various applications including structural and non-structural monitoring (Yang et al. 2022).

Advanced carbon-based materials, such as carbon black (CB), graphene, graphite, carbon nanotubes (CNTs), and various carbon materials derived from biomaterials, have been employed as conductive sensing layers due to their excellent conductivity and mechanical properties. CB, an amorphous form of carbon with a structure akin to disordered graphite, is a cost-effective and readily accessible material. It is used to enhance the mechanical properties and conductivity of composite materials when incorporated into flexible models (J. C. Huang, 2002). Many rubber-based sensors leverage materials such as nitrile rubber, silicone, and polydopamine-coated nanocomposites. These materials offer high sensitivity and durability, which are essential for dynamic sensing applications. For instance, nitrile rubber combined with carbon black can be used to fabricate biocompatible and flexible strain sensors (Yang et al. 2022b)

Different materials exhibit varying mechanical properties based on their inherent characteristics, including atomic and molecular forces or their specific shapes. The mechanical performance of flexible sensors is assessed by their stretch ability, pressure resistance, and fatigue endurance. Elongation, which measures the percentage increase in length compared to the original length at maximum stretch, is a widely used metric for evaluating the stretch ability of strain sensors (Shintake et al. 2018)

For instance, in structural application, the use of rubber materials in the development of dynamic sensors for structural health monitoring (SHM) has garnered interest due to rubber's inherent flexibility, durability, and damping properties. These characteristics make rubber an ideal candidate for sensors designed to detect and measure structural deformations and vibrations in real-time.

Dynamic sensors embedded in structural components monitor vibrations, strain, and other physical changes, providing crucial data for assessing structural integrity. Rubber-based sensors can be particularly advantageous due to their high elasticity and ability to return to their original shape after deformation, which ensures long-term reliability and accuracy.

One prominent application of rubber in SHM sensors is the development of piezoelectric and capacitive sensors. These sensors can convert mechanical strain into electrical signals, which are then analyzed to detect structural changes. The flexibility of rubber allows these sensors to be integrated into various structural components without compromising their mechanical properties.

Recent advancements in sensor technologies for SHM include the use of rubber-based microelectromechanical systems (MEMS). MEMS sensors combine rubber materials with miniature electronic components, offering high sensitivity and the ability to operate under harsh environmental conditions. These sensors are being explored for use in monitoring bridges, buildings, and other critical infrastructure (Ferreira et al. 2022), (Moreno-

Gomez et al. 2018), (Hassani & Dackermann 2023).

Meanwhile, for non-structural application, these sensors are extensively used in wearable electronics, such as electronic skins and health monitoring devices. They are capable of detecting strain, pressure, and even humidity, which are critical for applications ranging from body motion tracking to portable medical diagnostics (Liu et al. 2023), (Nguyen & Lee 2022)

Some recent developments include the creation of self-healing conductive composites, ultrastretchable hydrogels, and piezoelectric tactile sensor arrays. These innovations have improved the performance and functionality of rubber-based sensors, enabling them to detect a wide range of stimuli with high precision (Yang et al. 2022b ;, Seesaard & Wongchoosuk 2023).

Despite the progress, challenges remain in optimizing the performance and reliability of these sensors under various conditions. Future research is focused on enhancing their sensory materials, fabrication methods, and integration with other electronic systems to expand their applications and improve their market share. (Liu et al. 2023; Nguyen & Lee 2022)

SHM is a technique for assessing and monitoring structural health. SHM technique is a tool for detecting degradation of a structure applicable in aerospace, civil and mechanical infrastructure (Asthana et al. 2022). The SHM process involves selecting excitation techniques, sensor types and data acquisition known as health and usage monitoring system. Leveraging the abundance and versatility of NR, researchers have explored its unique characteristics to revolutionize SHM techniques. The application of natural rubber in SHM has demonstrated immerse potential for innovation and advancement.

This study may contribute to empowering Malaysia natural resources by producing sensing element using Malaysia's local rubber material. The critical challenge is evaluating the rubber elasticity, its relationship to structural response and the reliability of the developed strain measurement in accurately assessing the structural performance. Therefore, this study aims to design a strain measurement system to detect strain and stress, and the effectiveness of transducing element based on Wheatstone bridge to detect the elasticity of rubber samples.

Strain sensors for measuring strain have been widely used in conventional SHM system (L. Wang et al. 2017). The strain gauge is an electrical sensor that detects changes in force by measuring the corresponding variation in electrical resistance. This resistance change can be quantified in terms of either load or displacement. The effect of applied force is referred to as a stress and the resulting deformation as a strain (Johnson, n.d.). A Stress-Strain Curve is obtained by subjecting the material to various stress levels and measuring the resulting strain. Within a certain stress range, stress and strain have a linear relationship. If kept within this linear region, the material behaves elastically, meaning that removing the stress eliminates the deformation. However, exceeding the elastic limit leads to permanent deformation and eventual failure.

Strain gauges are commonly employed for measuring small strains (Leonarth & Ah Aldabbar, n.d.). A measurement system is required to accurately assess the strain gauge's resistance change. The Wheatstone bridge configuration is often utilized for this purpose, enabling precise measurements of electrical resistance in various ways. It allows for determining the absolute resistance value by comparing it to a known resistance and detecting relative changes in resistance. This proposed measurement system is particularly useful for signal conditioning applications where sensors exhibit resistance changes in response to varying process variables.

This paper aims to demonstrate the correlation between rubber elasticity and strain measurement. The objectives are firstly, to investigate the performance of rubber elasticity by accurately assessing the stress and strain behaviors, secondly, to quantify the output voltage generated through the examination of rubber elasticity under various conditions and lastly to evaluate the effectiveness of the strain measurement system in detecting and capturing the nuances of rubber elasticity. By addressing these objectives, this study endeavors to contribute to the understanding and advancement of rubber elasticity as a reliable means for measuring mechanical properties, thus potentially enhancing the applicability of such in SHM.

METHODOLOGY

PARAMETER OF RUBBER SAMPLES

A rheometer is a laboratory device used to measure the way in which a viscous fluid flows in response to applied forces. The rheometer measures the strength during the vulcanization which is needed for the deformation of the test specimen. Vulcanization describes the curing process of the raw ingredients of so-called green (uncured) rubber to form the final, cured rubber product with different mechanical and thermal properties (Adam et al. 2020). The change of the rubber strength over time is called the rheometer curve. These curves help to evaluate the quality of the rubber compound. The parameters of rheometer test for Rubber 1, 2 and 3 are shown in Table 1.

TABLE 1. Parameter of rheometer test

No	Variable	Rubber 1	Rubber 2	Rubber 3
1	Test Time (min)	30.00	30.00	30.00
2	Test Temp (˚C)	140	140	140
3	ML (dNm)	2.09	1.57	0.85
4	MH (dNm)	19.87	18.89	7.21
5	TS2 dNm (min)	3.10	3.37	6.53
6	T90 (min)	16.81	15.54	16.24
7	T95 (min)	20.59	19.00	18.95

The rheometer test is conducted at Engineering Laboratory, Malaysia Rubber Board (MRB). The rheometer test time for all rubber samples took 30 minutes with the temperature set at 140˚C. There are several following variables are obtained from rheometer test which are: ML (dNm), MH (dNm), TS2 dNm (min), T90 (min), T95 (min).

ML is the lowest torque value observed during the rheometer test, indicating the rubber's ability to flow under low-stress conditions. A higher ML value suggests that the rubber is less elastic and more prone to distortion when subjected to low stress. While MH represents the maximum torque measured during the test, indicating the rubber's resistance to deformation under high-stress conditions. A higher MH value indicates better elasticity and resilience, as the rubber can withstand higher stresses without significant deformation.

Next, TS2 tracks the time it takes for the torque to reach twice the ML value. It reflects the rubber's response time and its ability to transition from a liquid-like to a solid-like state when subjected to stress. A lower TS2 value indicates a faster elastic response and overall higher elasticity. T90 represents the time it takes for the torque to reach 90% of its maximum value (MH). It indicates the rubber's ability to return to its original shape after being stretched. A shorter T90 value suggests better shape recovery and elasticity. Similar to T90, T95 measures the time it takes for the torque to reach 95% of its maximum value (MH). It provides additional information about the rubber's recovery period and its capacity to regain its original form. A shorter T95 value indicates faster recovery and increased flexibility. (Gutierrez, S. C, 2019).

PROPOSED STRAIN MEASUREMENT SYSTEM

Our proposed method consists of two elements which are sensing and transducing elements. The setup of sensing element consists of strain gauge model KFGS-5-120-C1-11 L3M2R attached to Rubber 1, Rubber 2 or Rubber 3 as shown in Figure 1.

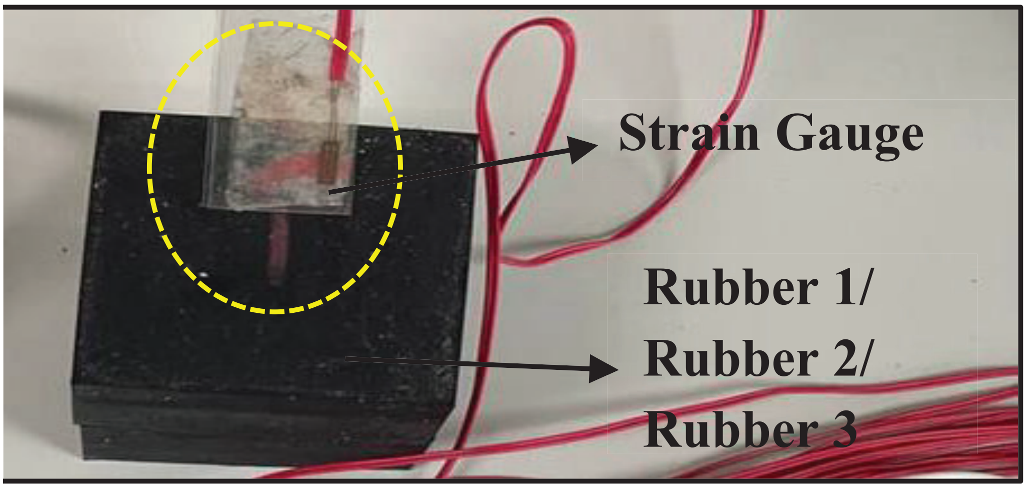


FIGURE 1. Setup of sensing element

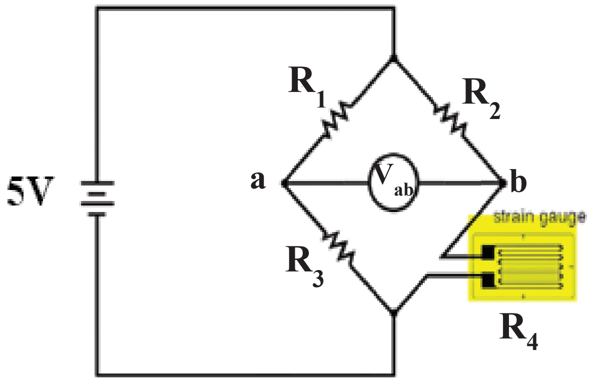


FIGURE 2. Schematic of transducing element

Figure 2 shows the schematic of Wheatstone bridge circuit in which the strain gauge KFGS-5-120-C1-11 L3M2R is connected in Quarter bridge configuration. The strain gauge attached to the Rubber as shown in Figure 1 represented as R4 in the schematic shown in Figure 2. The changes of resistance R4 resulted in the changes of voltage at point a and b which is known as Vab. R4 is the setup of sensing element shown in Figure 2. The changes of resistance R4 are caused by the stress and strain deformation from the Rubber when the load is applied.

In this case, the voltage (V_{ab}) between point a and b in the Wheatstone bridge shown in Figure 2 is simply as:

$$V_{ab} = \frac{VR_3}{R_1 + R_{3_a}} - \frac{VR_4}{R_2 + R_4} \qquad (1)$$

where V is bridge supply voltage.

Figure 3 shows the actual circuit of transducing element constructed on breadboard together with the sensing element. The value of resistors, R1, R2 and R3 used in the circuit are 22Ω, 50Ω and 50Ω respectively, and a R4 is the sensing element.

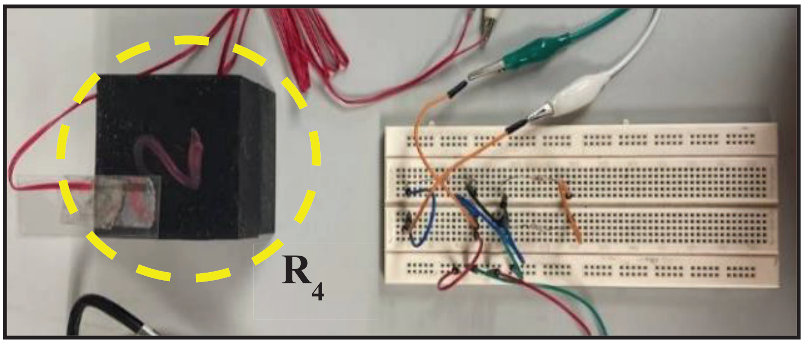


FIGURE 3. Transducing element constructed on breadboard

STRAIN MEASUREMENT SYSTEM USING DEWESOFT KRYPTON 3XSTG

In order to validate the performance of the proposed strain measurement system, an industrial measurement system known as DEWESoft Krypton 3xSTG is utilized. This instrument acts as preamplifiers in signal conditioning applications and convert the signals to EtherCAT data that is used within the control loop (EtherCAT Technology Group | KRYPTON 3xSTG, n.d.).

To acquire, digitize and process the data, the selected framework is developed using DEWESoft measurement system. This solution integrates data acquisition system (DAQ) hardware with highly customizable and modular software which is used to process the signals and estimate the parameters of interest (Rovai et al. 2023). DAQ Krypton 3xSTG is manufactured by DEWESoft and operated by DEWESoft (Pietrosanti et al. 2020). Krypton DAQ modules are designed for distributed measurements, bringing data acquisition closer to sensors, and offering several advantages over traditional systems. They enable the distribution of DAQ modules down to a single input channel.

The overall setup of transducing element using Krypton are shown in Figure 4. In Krypton device, the transducing element which is a quarter-bridge circuit is coded in DEWESoft software. The strain gauge is connected to Channel 2 on the Krypton 3xSTG as shown in Figure 5.

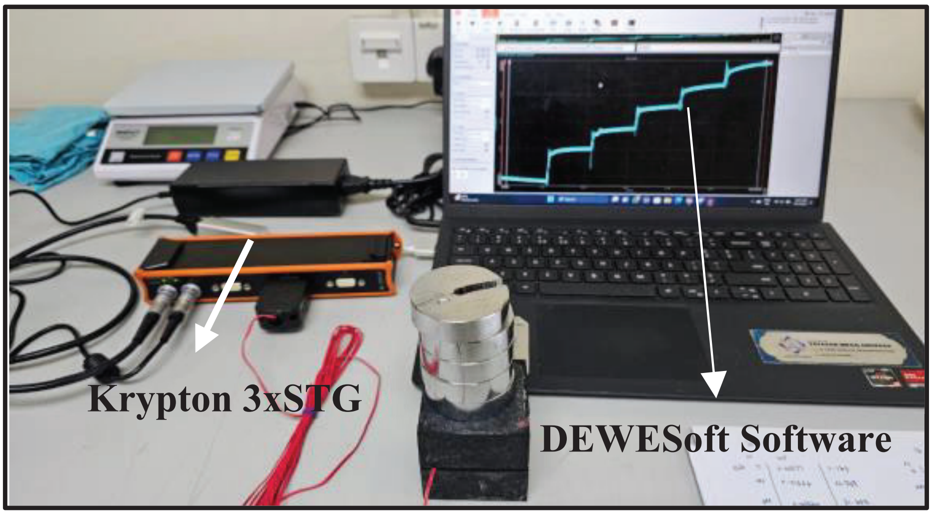
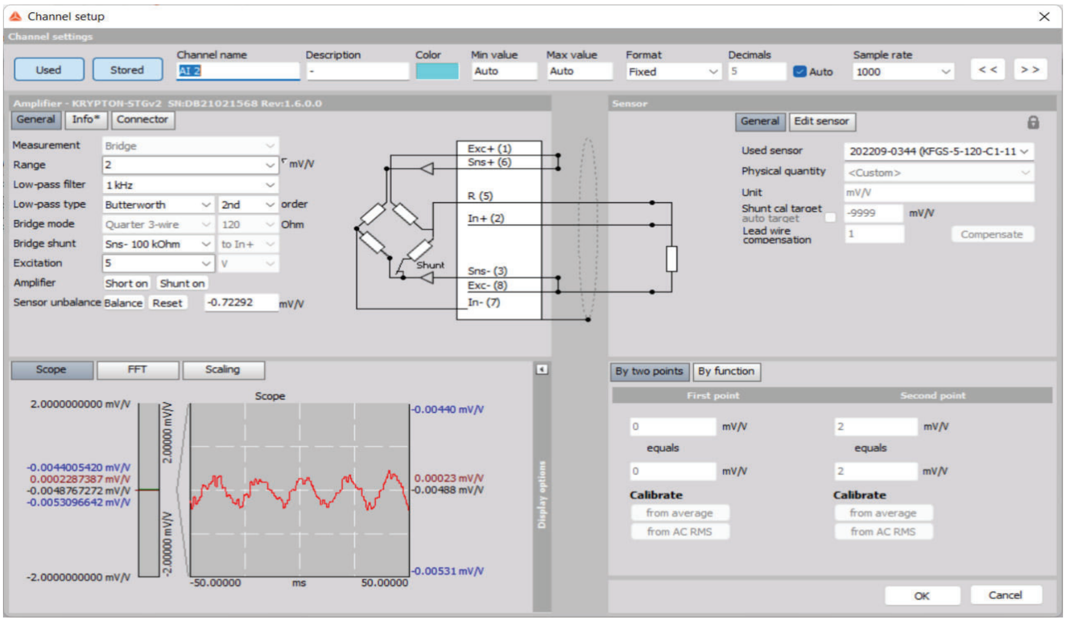


FIGURE 4. Transducing element constructed using Krypton


Channel setup

Channel settings

Channel name: AI 2
Description: -
Min value: Auto
Max value: Auto
Format: Fixed
Decimals: 5 ☑ Auto
Sample rate: 1000

Amplifier - KRYPTON-STGv2 SN:DB21021568 Rev:1.6.0.0

Measurement: Bridge
Range: 2 mV/V
Low-pass filter: 1 kHz
Low-pass type: Butterworth 2nd order
Bridge mode: Quarter 3-wire 120 Ohm
Bridge shunt: Sns- 100 kOhm to In+
Excitation: 5 V
Sensor unbalance: -0.72292 mV/V

Sensor

Used sensor: 202209-0344 (KFGS-5-120-C1-11
Physical quantity: <Custom>
Unit: mV/V
Shunt cal target: -9999 mV/V
auto target ☐
Lead wire compensation: 1

First point: 0 mV/V equals 0 mV/V
Second point: 2 mV/V equals 2 mV/V

FIGURE 5. Quarter bridge circuit coded in DEWESoft software

LOAD TEST ON RUBBER SAMPLE

Figure 6 shows the load applied to the sensing element ranging from 2N, 4N, 6N, 8N and 10N. As mentioned earlier, the sensing element consists of strain gauge attached to the Rubber. The load applied to the rubber created a stress and strain deformation which transduces changes of voltage, V_{ab} across Wheatstone bridge (refer to Figure 2). This change of voltage is measured using multimeter as setup in Figure 3 and validated with Krypton which is industrial measurement system as setup in Figure 4.

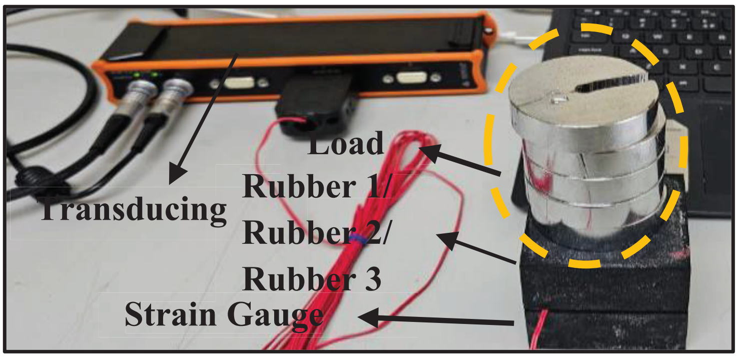


FIGURE 6. Setup of load test on the complete measurement system

RESULTS AND DISCUSSION

TEMPORAL ANALYSIS

This section presents the results of the proposed strain measurement system and the results of the strain measurement system using Krypton 3xSTG. The performance of sensing elements for Rubber 1, Rubber 2 and Rubber 3 are compared for both strain measurement systems. The results obtained from the proposed strain measurement system using the multimeter are shown in Figure 7. Meanwhile the result from strain measurement system using DAQ Krypton is shown in Figure 8. The voltage, Vab shows linearly increases when the load applied increases. In each graph, the performance of Rubber 1, Rubber 2 and Rubber 3 as a sensing element is compared. The slope performance shown in Figure 7 and Figure 8 represents strain sensitivity of rubber material when load is applied.

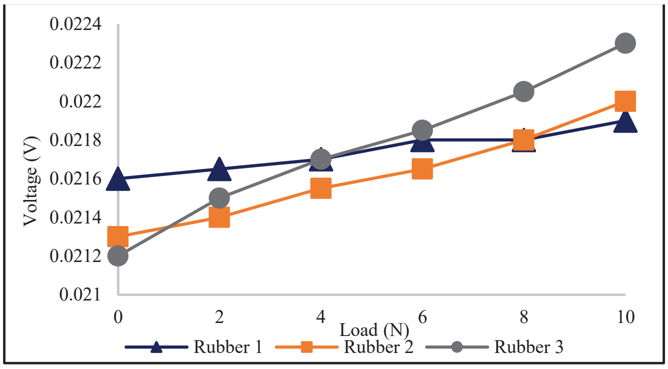


FIGURE 7. Performance of the transducing element measured using proposed strain measurement system.

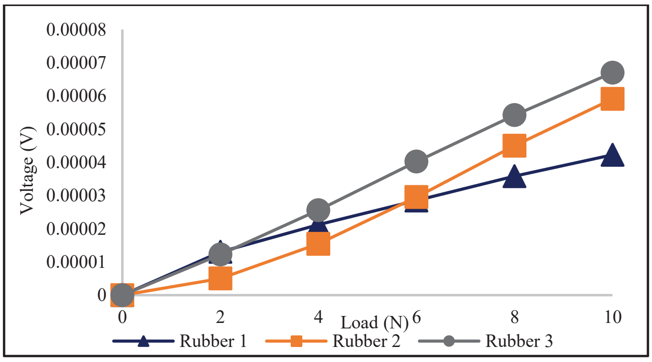


FIGURE 8. Performance of the transducing element measured using Krypton 3x STG.

Based on the graphs in Figure 7 and Figure 8, it can be concluded that when a certain amount of load is applied, Rubber 3 exhibits the highest voltage values followed by Rubber 2 and Rubber 1. It is observed that the performance of proposed strain measurement system gives almost the same pattern as strain measurement system using Krypton. It is because when the load is applied, which produces a deformation of strain gauge that attaches to rubber and the resistance element. This deformation is indicated through a measurement of the change in the resistance of the element (Design and Development of New Electrostatic Voltmeter Using Strain Gauge, n.d.). For result in Figure 7, it indicates the expected pattern appears when minimum 8N load is applied. However, in result in Figure 8, the expected pattern started to appear when the 6N load is applied.

Strain gauges are sensors based on electrical resistance, which generate a variation in its electrical resistance when subjected to a deformation in its length. When attached to a body under deformation the strain gauge undergoes the same deformation. In this way the increase its size, consequently generating a variation in the initial resistance of the strain gauge, being the variation of the resistance with the deformation linear. In the case of deformation instrumentation, where the resistance variations of the strain-gauges are minimal, the Wheatstone bridge circuit is used (Kalpana & Siddeswara Prasad, 2014).

From the voltage obtained in Figure 9 and Figure 10 below, the performance resistance of the proposed strain measurement system is observed through Equation (1.1). This proves that when the load is applied, the deformation causes a change in resistance.

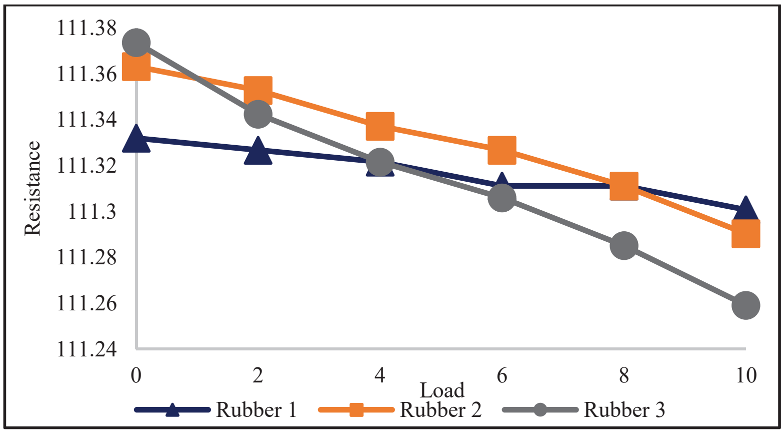


FIGURE 9. Performance of resistance measured using proposed strain measurement system when applied load

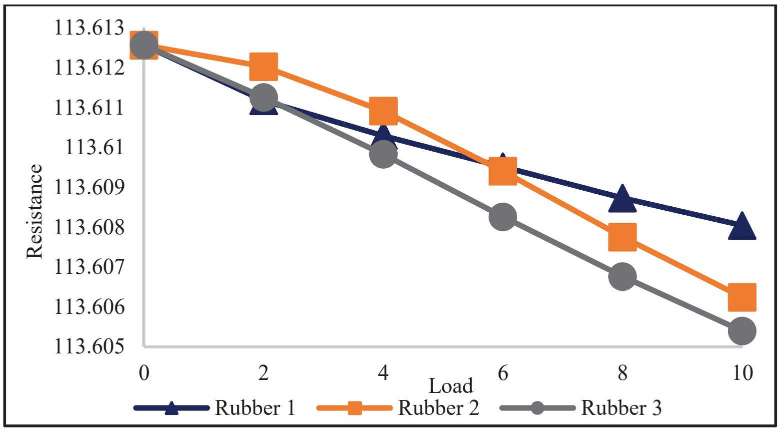


FIGURE 10. Performance of resistance measured using Krypton 3x STG when applied load

The simulation of the Wheatstone bridge circuit in Proteus was built with supply voltage, 5V and the resistors in bridge are by R1 is 22ohms, both R2 and R3 is 50ohms and R4 are as strain gauge. The DC voltmeter was used to define the voltage between points a and b where it can be defined by using manual calculation.

The result of voltage from DC voltmeter between points a and b which the simulation gives the same reading with manual calculation as shown in Figure 11. It shows that the circuit connection of Wheatstone bridge in Proteus simulation and the manual calculation gives the same value has been proven correlated with Equation (1.1). The bridge voltage in Figure 12 is clearly nonlinear for large scale changes in resistance.

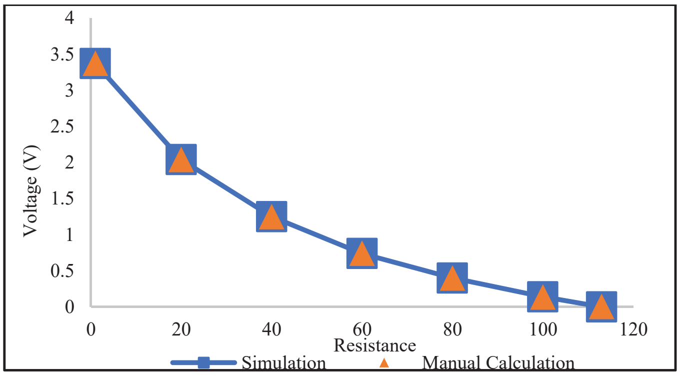


FIGURE 11. Voltage performance between simulation and theoretical.

Based on Figure 12 and Figure 13, the performance voltage responding to resistance for Rubber 1, Rubber 2 and Rubber 3 are almost the same as the simulation on Proteus. The small ranges of resistance change, then the voltage is nearly linear (Johnson, n.d.).

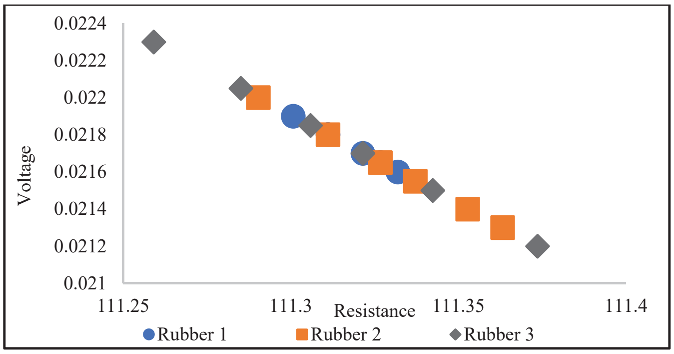


FIGURE 12. Performance of voltage responding to resistance for proposed strain measurement system

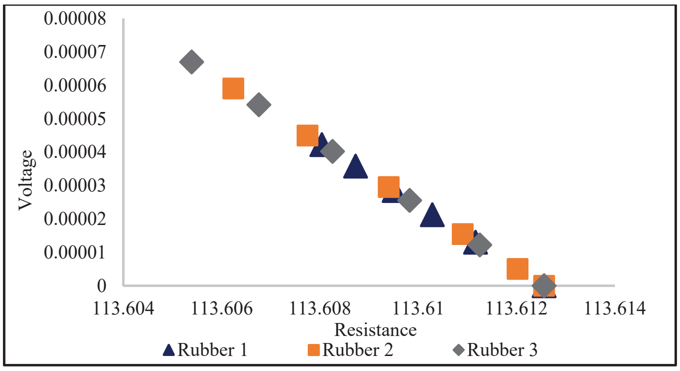


FIGURE 13. Performance of voltage responding to resistance measured using Krypton 3xSTG

The voltage measured serves as an indicator of the rubber sample's ability to deform and subsequently return to its original shape upon the load is applied. Higher voltage values indicate greater deformation, hence proving high elasticity. It can be related to the relationship of the strain and load where there is an increasing compressive strain that correlates well with the applied load (Täljsten et al. 2008). Rubber samples demonstrate high elasticity and can undergo significant deformation under stress and return to its original shape once the stress is removed (Gent, 2005). Therefore, Rubber 3 possesses the highest elasticity followed by Rubber 2 and Rubber 1. These results agree to the Rheometer test results (TS2) of the rubber samples in which Rubber 3 has the longest time value (6.53 dNm/min) followed by Rubber 2 (3.37 dNm/min) and Rubber 1 (3.10 dNm/min) as indicated in Table 2.

Overall, the proposed strain measurement system is able to detect the stress and strain of Rubber 1, Rubber 2 and Rubber 3 responding to applied load.

TABLE 2. Sensitivity of strain measurement system

Rubber	Parameter Rheometer test (TS2 – dNm/min)	Sensitivity proposed measurement system (mV/N)	Sensitivity measurement system using Krypton (mV/N)
1	3.10	0.0293	4.097
2	3.37	0.0686	6.132
3	6.53	0.1043	6.792

Figure 14 and Figure 15 represents a summary derived from Table 2. The pattern of sensitivity performance for Rubber 1, Rubber 2 and Rubber 3 using proposed strain measurement systems are almost the same as the strain measurement systems using Krypton when the load applied. Where the pattern of sensitivity for Rubber 1, Rubber 2 and Rubber 3 is slightly increased same as strain measurement system using Krypton. However, the sensitivity value using the proposed strain measurement system is very small compared to strain measurement systems using Krypton, this may be because the proposed strain measurement system needs the amplifier to amplify the signal. It can conclude that the proposed strain measurement system using rubber sample as the sensing element is able to measure the load in the range of 2N to 10N.

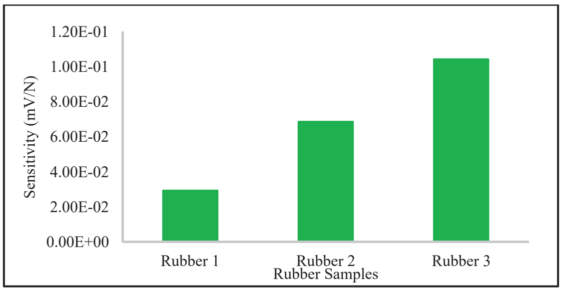


FIGURE 14. Sensitivity rubber samples using proposed strain measurement systems

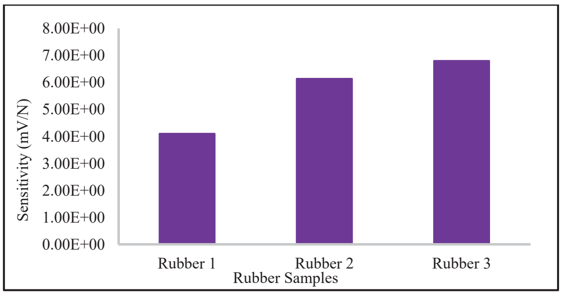


FIGURE 15. Sensitivity rubber samples strain measurement systems using Krypton

The graph in Figure 16 compares the percentage elasticity of rubber sample using rheometer test and the proposed strain measurement system. For rubber 1 the elasticity performance between the proposed strain measurement system is slightly lower than rheometer test value. Meanwhile for rubber 2, the elasticity performance of the proposed strain measurement system is slightly higher from the rheometer test result and for rubber 3, the proposed strain measurement system is almost same with the value obtained in rheometer test. Despite this inconsistency, the elasticity percentage for the proposed strain measurement system gives the same pattern performance as the result rheometer test. It further demonstrates the validity of the proposed strain measurement system to detect stress and strain of the rubber material responding to applied load.

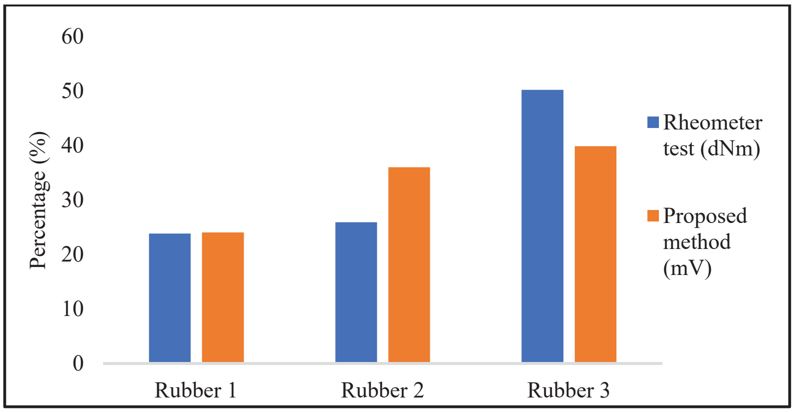


FIGURE 16. Comparison percentage elasticity of rubber samples using two different tests.

CONCLUSION

This study has successfully demonstrated the correlation between rubber elasticity and strain measurement. The strain gauge sensor has proven effective in detecting and measuring the strain experienced by Rubber 1, Rubber 2 and Rubber 3. Besides that, this study intends to obtain the output voltage by examining rubber elasticity. From the analysis performed, the value of output voltage was influenced by the changes of the resistance on the strain configuration. The variation of the value of load gives the different output voltage. Other than that, this research is to evaluate the effectiveness of strain measurement system to detect rubber elasticity. This unique property makes rubber an excellent sample for strain and stress measurements. The strain sensors conducted in this project effectively detect and measured the deformation or strain experienced by rubber when subjected to external forces.

In the experimental, when load is applied to a rubber samples, the result of strain is measured. It has been observed that as the load on the rubber samples increases, the measured strain detected by the strain gauge, also increases. This leads to an increase in the bridge output voltage, which serves as a reliable indicator of the applied strain. Among the three types of rubber samples tested, Rubber 3 exhibits the highest percentage value of bridge output voltage, making it the most elastic compared to the other two rubber for strain measurement. It can be compared to rheometer test where Rubber 3 has the lower TS2 value and the highest percentage torque which indicates a faster elastic response and overall higher elasticity. It can be concluded that the proposed strain measurement system that has been developed is giving almost the same percentage increase of elasticity compared to the rheometer test.

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DECLARATION OF COMPETING INTEREST

None.

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