# Comparison of the Modulus of Elasticity Values of Mortar Specimens with Crumb Rubber Replacing Sand by 10%, 15%, and 20% Before and After Heating at 150 $^{O}$C

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## ABSTRACT

**This study investigates the use of waste tires, specifically crumb rubber, as a substitute for sand in mortar compositions. The performance of its mechanical properties is analyzed by measuring the modulus of elasticity of normal mortar specimens and rubber crumb mortar with 10%, 15%, and 20% variations, under normal conditions and after heating to 150 °C. The research method uses a 14-sample experimental design to test the cylinder compressive strength. Data were analyzed using qualitative descriptive statistics. The results indicate that the elastic modulus of crumb rubber mortar specimens with 10%, 15%, and 20% content is lower before and after heating to 150°C, exhibiting higher elasticity at 14 days. Conversely, the elastic modulus of 10% crumb rubber mortar before heating exhibits superior elasticity, durability, and increased deformation compared to normal mortar and other mortar variations after 28 days. These findings provide new knowledge about using crumb rubber as a mortar additive in sustainable construction and promote the innovative use of recycled materials.**

***Keywords-crumb rubber mortar mechanical properties; modulus of elasticity; sustainable material; recycled materials***

## I. INTRODUCTION

The elastic modulus is a characteristic of materials, which measures their stiffness. Knowing this parameter, engineers and designers can determine the behavior of a material under heavy loads, especially in aerospace, automotive, and construction industries, where they experience different pressures. Materials with a higher elastic modulus are considered stiffer and more resistant to deformation, whereas those with a lower modulus are considered more flexible. For instance, when designing bridges, engineers must consider the elastic modulus of the materials used to certify their ability to withstand stress and strain from traffic and weather, and thus to ensure stability and prevent deformation due to heavy loads [1]. The elasticity of a material can be affected by external factors, such as temperature and humidity, with the environmental conditions causing expansion or contraction [2-4]. Manufacturers must consider these factors when designing and testing their products to ensure functionality under various conditions [5-7]. Temperature plays a significant role in the flexibility of a material, along with the composition and processing method. The connection between the molecular structure and elasticity allows engineers and manufacturers to design materials that meet specific needs more effectively. For example, the microstructure of steel is analyzed before and after heat treatment, and the corrosion rate increases due to the hardening effect of the steel. Tempering water-cooled steel at 450 °C for 1 h substantially improves the corrosion resistance of 0.27% carbon steel [8-12]. Industrial sub products, such as fly ash and slag, can be added to the mortar in order to improve its properties [13-15] while reducing the environmental impact by decreasing landfill waste. Furthermore, using recycled materials from coal combustion or silicon metal production can lower costs, making the construction practices more sustainable. Silica fume can improve the mechanical and durability properties of concrete [16-18]. Partially replacing cement in mortar mixes with fly ash and silica fume can lower the greenhouse gas emissions produced during production. Additionally, using these materials can increase the mortar's strength and durability, resulting in longer-lasting structures that require less maintenance over time [19-24]. This research aims to evaluate and analyze the comparative effectiveness of normal mortar and crumb rubber mortar specimens with 10%, 15%, and 20% variations under normal conditions and after being heated at 150 °C [25, 26]. The primary objective is to determine if heating crumb rubber at these percentages improves the mortar's elasticity compared to normal crumb rubber and heated mortar [27-29]. Through this comparative analysis, the research aims to identify changes in the physical and mechanical properties of the mortar due to different treatments applied to the latter. The research also aims to identify changes in the physical properties of the mortar owing to different treatments with varying crumb rubber content in mortar specimens before and after heating at 150°C. Additionally, the present research will generate quantitative empirical data that can be used to optimize the use of crumb rubber in row house walls in terms of damage damping capacity. The findings of this work are expected to contribute significantly to the development of more sustainable and efficient building materials. While previous research showed that crumb rubber improves the flexibility of mortar specimens, its elastic properties often pose challenges in achieving homogeneous mixing. Other studies have investigated the benefits and challenges of using recycled materials in construction, including their impact on modulus of elasticity strength before and after heat treatment at 150 °C for an extended period. The heating process of crumb rubber mortar has become a popular research topic, as it can modify the physical properties of crumb rubber, such as surface roughness and elasticity. It has been demonstrated that the changes in physical properties due to heating can improve the performance of composite materials. However, deeper testing applications have not been fully covered, such as testing and evaluating the differences in the elastic modulus performance of mortar specimens with varying amounts of crumb rubber before and after heating to 150 °C. More comprehensive and focused research is needed to understand how heat treatment influences the elastic modulus capacity of crumb rubber mortar according to the SNI standards [30, 31].

## II. MATERIALS AND METHODS

### *A. Materials*

In this study, Portland Type I cement (Tonnasa Cement) is used, which functions as the primary binder, along with fine sand, characterized by a gradation in accordance with the ASTM C33 standards. Water is utilized as a mortar control, adhering to the SNI guidelines. The T.03-3449-2002 model was modified by substituting sand with crumb rubber obtained from recycled used tires, which, in its standard condition and without additional treatment, was ground and sieved to a size ranging from 0.15 mm to 4.75 mm. This process was performed with crumb rubber substitution rates of 10%, 15%, and 20% by weight of sand. Subsequently, the specimens were subjected to a NaOH solution to assess the mechanical properties of the mortar mixture, with particular emphasis on its elastic modulus. The rubber from the mortared crumb has been maintained in a standard condition, requiring no additional treatment. Crumb rubber is subjected to a heating process at 150 °C for a duration of 1 h, thereby altering its physical properties.

### *B. Method*

Fourteen 10 cm × 20 cm mortar cylinder samples were used to assess the mechanical parameters of the compressive strength and modulus of elasticity, being tested at 14 and 28 days. The control variables consist of two specimens, with crumb rubber substitution samples of 10%, 15%, and 20%, before and after being heated at 150 °C in an oven. Data analysis was conducted by comparing the compressive strength and elastic modulus of the mortar specimens based on variations in crumb rubber content. The equipment selected for this study includes a Universal Testing Machine (UTM) and a Linear Variable Displacement Transducer (LVDT) in order to measure the displacement and vibrational energy of the specimen, with the maximum deformation value recorded [30-32]. The modulus of elasticity is:

$$E = \frac{\sigma}{\varepsilon} \tag{1}$$

where $\varepsilon = \frac{\Delta L}{L_0}$ is the stretch, $\sigma = \frac{F}{A}$ is the voltage, $A=\pi r^2=\pi (0.05)^2\approx 0.00785$ m$^2$ is the cross-sectional area, the cylinder diameter is 0.1 m (radius of a cylinder 0.05 m), and the initial length ($L_0$) is 0.2 m.

### *C. Mortar Material Preparation*

The analysis of mortar aggregates is conducted in accordance with the SNI 03-4142-1996 standards, while the testing procedures for specific gravity and dry surface absorption align with the standards outlined in SNI 03-1970-1990. The sand used in the construction comes from Gowa Regency, South Sulawesi, while the mortar is formed utilizing

Tonnasa cement. The standard mortar mixture was prepared in accordance with the SNI T03-3449-2002 guidelines, while the sand substitution materials used crumb rubber variations of 10%, 15%, and 20%, as shown in Table I.

TABLE I. MORTAR SPECIMEN MEASUREMENT

| Number | Mortar specimen material | Normal mortar specimen | CR 10% mortar specimen | CR 15% mortar specimen | CR 20% mortar specimen |
|---|---|---|---|---|---|
| 1 | Tonnasa cement | 394 kg | 394 kg | 394 kg | 394 kg |
| 2 | Water | 180 kg | 180 kg | 180 kg | 180 kg |
| 3 | Sand fine aggregate | 790 kg | 711 kg | 671.5 kg | 632 kg |
| 4 | Crumb rubber | | 79 kg | 118.5 kg | 158 kg |

SNI. T03-3449-2002

### D. *Sample Creation Application*

The calculation of the mixture proportions is adjusted to the sample volume dosage, which is 14 mortar specimens. The dry ingredients (cement, sand, and crumb rubber) were thoroughly amalgamated in a bowl using a mechanical mixer for a period of 2 min. Water was added gradually, and the mixture was agitated for 3 min until it was homogeneous. The mixture should be stirred continuously until the desired consistency is sufficiently thick to be placed in the mold, yet not excessively dry. Following the amalgamation of cement and sand, the addition of crumb rubber occurs, according to the prescribed proportion, as displayed in Figure 1.

### E. *Pouring Process in Mold*

Before placing the mortar into the cylinder, it is important to apply a lubricant to the sample to ensure ease of release following the hardening process. Subsequently, the mortar mixture is carefully and evenly deposited into the mold. The absence of air bubbles is a prerequisite for this process, while the leveling process was carried out using a vibrator to ensure that the mortar was optimally filled into the mold, thereby reducing porosity.

### F. *Mortar Specimen Care*

Once the mortar is thoroughly mixed, it is transferred into cylindrical molds and allowed to rest for 24 h. For the drying process, the samples were covered with plastic to ensure adequate adhesion between the mortar aggregate particles, as depicted in Figure 2. After a 24-h period, the mortar cylinder molds were stored for curing for 14 and 28 days, after which the mechanical parameters of the mortar cylinders were investigated in order to determine their compressive strength.

### G. *Testing Process*

The preparation of the specimens was carried out using the compressive strength test method and mortar deformation measurement to analyze changes in shape, stress, strain, and the elastic modulus of cylindrical mortar. A UTM with a capacity of 1000 kN and two LVDT devices were used to measure the level of elasticity. The loading was applied until the mortar cylinder specimen cracked, and the value (kN) was recorded, in order to determine the compressive stress, strain, and elastic modulus of the mortar, as shown in Figure 3. A comparative analysis was conducted on the mechanical parameter outcomes of normal mortar and of mortar containing 10%, 15%, and 20% crumb rubber, both before and after heating at 150 °C, in order to determine the impact of crumb rubber heating on the elastic modulus of the mortar.


Fig. 1. (a) Sand aggregate screening process, (b) checking the sand aggregate content using a color disc tool, (c) weighing sand aggregate using a funnel, (d) weighing crumb rubber aggregate for mortar specimen mix, (e) mixing normal mortar and crumb rubber mortar variations, (f) mortar mold preparation process on a cylinder.

## III. RESULTS AND DISCUSSION

### A. *Comparison of the Compressive Strength of Normal and Crumb Rubber Mortar Specimens Before and After Heating at 150 °C*

The findings of the analysis of the mechanical parameters of conventional mortar reveal higher values relative to those observed in mortars with crumb rubber as a substitute. This is due to the structural characteristics and physical properties of the standard mortar, which exhibits increased compactness and homogeneity, thereby providing enhanced load-bearing capacity against compressive forces.

(a) (b)

Fig. 2. (a) Mortar specimen treatment with a cylinder using plastic on the first day in a water bath, (b) on the second day, the mortar specimens were removed from the cylinder for curing in a water soaking bath.

(a) (b) (c) (d)

Fig. 3. (a) The process of heating the cylinder in an oven at a temperature of 150 $^{O}$C, (b) preparation of tool settings and cylinder testing using UTM and LVDT tools, (c) the process of weighing cylindrical samples before the testing process using a weighing tool, (d) compressive strength testing process using UTM and LVDT.

At concentrations of 10%, 15%, and 20% by weight, a decline in compressive strength was observed for mortars with crumb rubber. This decline indicates a shift in the aggregate composition, leading to a reduction in the mechanical strength of the mortar. The compressive strength of crumb rubber mortar after heating exhibits distinct characteristics compared to the strength prior to heating. The mechanical properties of mortar may be influenced by thermal exposure due to the occurrence of thermal alterations in the material, particularly in crumb rubber, which exhibits thermoplastic characteristics.

### *B. Qualitative Result Analysis*

Table II presents a total of 14 mortar cylinder samples that were examined to evaluate their mechanical parameters and compressive strength after 14 days. The mean values suggest that mortar cylinder samples with 10% sand substitution using crumb rubber, both before and after heating, exhibit reduced compressive strength or stress parameters at 14 days. This reduction is evidenced by an average decrease of 55.44% and 34.12%, respectively, in comparison to the standard mortar specimens. In a similar manner, after a 28-day period, the mechanical strength parameters of the compressive cylinder demonstrated a decline of 45.59% and 49.78%, respectively, when heated at 150 °C in comparison to the standard mortar samples.

TABLE II. COMPRESSIVE STRENGTH PARAMETERS OF CYLINDER SAMPLES, WITH 10% CONCENTRATION, BEFORE AND AFTER HEATING AT 150 $^{O}$C, AFTER 14 AND 28 DAYS

| **Variation** | | **Normal** | **10% (before heating at 150 ºC)** | **10% (after heating at 150 ºC)** |
|---|---|---|---|---|
| Compressive strength value of damping power (14 days) (MPa) | | 13.51 | 6.02 | 8.90 |
| Increase/decrease | | - | -55.44 % | -34.12 % |
| Information | | - | Downs | Downs |
| Compressive strength value of damping power (28 days) (MPa) | | 20.31 | 11.05 | 10.20 |
| Increase/decrease | | - | -45.59 % | -49.78 % |
| Information | | - | Downs | Downs |
| Change in length (ΔL) (14 days) (m) | | 0.00128 | 0.0031 | 0.00149 |
| Change in length (ΔL) (28 days) (m) | | 0.00355 | 0.00279 | 0.00062 |

The research analysis indicates that the addition of crumb rubber to the mortar mix influences the durability of the mortar specimens. The samples with sand substitution exhibited higher levels of damage and lower heat resistance, indicating that the use of crumb rubber may not be suitable for applications where high temperatures occur. This study examines the impact of crumb rubber on the durability of specimens in diverse situations to offer critical results for construction professionals trying to increase the sustainability and resilience of projects. As depicted in Table III, a total of 14 mortar cylinder samples were examined to assess their mechanical parameters and compressive strength at 14 days. The mean values indicate that cylindrical mortar samples with 15% sand substitution using crumb rubber, both before and after heating, exhibited reduced compressive strength or stress parameters at 14 days, with an average decrease of 59.66% and 57.81%, respectively, compared to the standard mortar specimens. In a similar manner, at the 28-day mark, the mechanical strength parameters of the compressive cylinder demonstrated a decline of 69.97% and 53.67%, respectively, before and after heating at 150 °C in comparison to the standard mortar samples. This underscores the necessity of comprehensive testing and evaluation before the integration of crumb rubber into construction projects where thermal resistance is vital. While the usage of rubber crumbs may enhance the resistance and the sound absorption, it is important to examine how these modifications could impact the overall performance of the construction material under different environmental conditions.

As presented in Table IV, the mean values suggest that samples with 20% concentration of crumb rubber, both before and after heating, exhibit reduced compressive strength or stress parameters at 14 days. These samples show an average decrease of 66.62% and 57.36%, respectively, in comparison to standard mortar specimens. In a similar manner, at the 28-day mark, the mechanical parameters exhibited a decline of 60.46% and 56.33%, respectively, after being subjected to a temperature of 150 °C in comparison to the standard mortar samples. Mortar samples with 20% crumb rubber, heated at 150 °C for 14 and 28 days, exhibited an increase of 27.72% and 9.47%, respectively, compared to the 20% samples before heating. These findings demonstrate that adding 20% crumb rubber to the mortar mix enhances its mechanical strength and increases its resistance to high temperatures. Furthermore, it is important to examine the potential of crumb rubber usage in decreasing waste from used tires.

TABLE III. COMPRESSIVE STRENGTH PARAMETERS OF CYLINDER SAMPLES, WITH 15% CONCENTRATION, BEFORE AND AFTER HEATING AT 150 °C, AFTER 14 AND 28 DAYS

| **Variation** | **Normal** | **15% (before heating at 150 °C)** | **15% (after heating at 150 °C)** |
|---|---|---|---|
| Compressive strength value of damping power (14 days) (MPa) | 13.51 | 5.45 | 5.70 |
| Increase/decrease | - | -59.66% | -57.81% |
| Information | - | Downs | Downs |
| Compressive strength value of damping power (28 days) (MPa) | 20.31 | 6.10 | 9.41 |
| Increase/decrease | - | -69.97 % | -53.67 % |
| Information | - | Downs | Downs |
| Change in length (ΔL) (14 Days) (m) | 0.00128 | 0.00159 | 0.00152 |
| Change in length (ΔL) (28 Days) (m) | 0.00355 | 0.0004 | 0.00076 |

TABLE IV. COMPRESSIVE STRENGTH PARAMETERS OF CYLINDER SAMPLES, WITH 20% CONCENTRATION, BEFORE AND AFTER HEATING AT 150 °C, AFTER 14 AND 28 DAYS

| **Variation** | **Normal** | **20% (before heating at 150 °C)** | **20% (after heating at 150 °C)** |
|---|---|---|---|
| Compressive strength value of damping power (14 days) (MPa) | 13.51 | 4.51 | 5.76 |
| Increase/decrease | - | -66.62 % | -57.36 % |
| Information | - | Downs | Downs |
| Compressive strength value of damping power (28 days) (MPa) | 20.31 | 8.03 | 8.87 |
| Increase/decrease | - | -60.46 % | -56.33 % |
| Information | - | Downs | Downs |
| Change in length (ΔL) (14 Days) (m) | 0.00128 | 0.00173 | 0.00133 |
| Change in length (ΔL) (28 Days) (m) | 0.00074 | 0.00173 | 0.00133 |

### *C. Results of Elastic Modulus Calculation for Normal and Crumb Rubber Mortar Before and After Heating at 150°C*

Table V presents the results of the elastic modulus calculation, before and after heating at 150 °C. A comparison of the elastic modulus calculations for 15% crumb rubber mortar before and after heating at 150 °C reveals a reduction of 67.32% and 64.47%, respectively, in relation to the elastic modulus of normal mortar at 14 days. This observation signifies that the standard mortar exhibits high rigidity, low elasticity, and inadequate energy absorption, resulting in minor deformation and an increased susceptibility to fracture. In contrast, the 15% crumb rubber mortar demonstrated a low elastic modulus, high flexural strength, excellent energy absorption capacity, enhanced elasticity, and significant deformation before and after heating, indicating an enhanced resistance to fracture. A comparison of the elastic modulus calculations for 20% crumb rubber mortar before and after being heated at 150 °C reveals a decrease of 75.32% and 68.45%, respectively, in relation to the elastic modulus of normal mortar at 14 days. This observation signifies that standard mortar demonstrates high rigidity, is inelastic, and presents negligible deformation, rendering it susceptible to fracture. In contrast, the 20% crumb rubber mortar displays a low elastic modulus, high flexural strength, excellent energy absorption capacity, enhanced elasticity, and significant deformation.

The experimental findings show that the 20% crumb rubber mortar displays higher resistance to higher temperatures compared to the conventional mortar. At a temperature of 150 °C, the 20% crumb rubber mortar exhibits a substantial retention of its mechanical properties, while the conventional mortar demonstrates a substantial decline. This suggests that the addition of crumb rubber to the mortar may enhance its resistance to high temperatures, rendering it suitable for construction applications that demand extreme heat resilience. Furthermore, in concentrations of 10%, 15%, and 20%, crumb rubber reduces the environmental impact of the mortar. The usage of 20% crumb rubber mortar can serve as an ecological and efficient alternative in the construction industry. The findings of this study show that the usage of 20% crumb rubber mortar exhibits a superior elastic modulus compared to the standard mortar after 28 days. The elastic modulus of 10% mortar exhibited a 186.74% increase following the application of heat in comparison to the elastic modulus of conventional mortar. The elastic modulus of mortar with 15% and 20% concentration, both before and after heating at 150°C, increased by 165.82%, 115.82%, 89.12%, and 16.25%, respectively, compared to the elastic modulus of the normal mortar. Mortar samples with variations of 15% and 20%, before and after heating, after 28 days, exhibited low elasticity, high stiffness, and a propensity for cracking. Additionally, these samples demonstrated minimal deformation compared to the standard mortar, which also exhibited a low elastic modulus at 28 days. Overall, mortars comprising 15% and 20% crumb rubber exhibit reduced compressive strength in comparison to conventional mortars, modifying the material's mechanical properties. However, the enhancement in the elastic modulus of crumb rubber mortar following heating at 150 °C reveals the possibility of enhancing the material's performance in construction applications. The elastic modulus of the 10% crumb rubber mortar specimen at 28 days exhibited a 30.97% decrease compared to the regular mortar before heating. Mortar containing 10% crumb rubber exhibits increased elasticity, higher energy absorption capacity, and excellent deformation resistance compared to the conventional mortar. This emphasizes the inherent rigidity of the typical mortar, making it susceptible to cracking under excessive loads. However, this reduction actually increases ductility and resistance to initial cracking. Conversely, the addition of excess crumb rubber reduces the mechanical strength and does not result in a substantial enhancement of elasticity.

The heating process of mortar with crumb rubber results in a reduced stiffness compared to the standard mortar. This phenomenon is attributed to the elastomeric properties of the crumb rubber, which can absorb thermal energy and minimize the stress concentration within the mortar matrix. According to the findings of previous research, while normal mortar has been shown to possess a high modulus value, its performance is significantly reduced after heating due to its brittle nature. Conversely, crumb rubber-based mortar retains a substantial degree of flexibility, exhibits a lower modulus, but demonstrates enhanced stability, particularly following the initial and secondary heating cycles. The most significant distinction is that the 10% crumb rubber mortar displays the most balanced combination of elastic modulus, deformation, and thermal resistance, whereas the standard mortar demonstrates excellence in rigidity but exhibits deficiencies in deformation and temperature resistance. This finding indicates that the optimal usage of crumb rubber (approximately 10%) can serve as a viable strategy to produce mortar that demonstrates enhanced durability, flexibility, and adaptability to extreme environmental conditions without significantly compromising the mechanical performance.

TABLE V. MECHANICAL PARAMETERS OF THE MODULUS ELASTICITY OF CYLINDER SAMPLES , WITH 10%, 15% AND 20% CONCENTRATION, BEFORE AND AFTER HEATING AT 150 $^{O}$C, AFTER 14 AND 28 DAYS

| **Variation** | **Normal** | **10% (before heating at 150 °C)** | **10% (after heating at 150 °C)** | **15% (before heating at 150 °C)** | **15% (after heating at 150 °C)** | **20% (before heating at 150 °C)** | **20% (after heating at 150 °C)** |
|---|---|---|---|---|---|---|---|
| Modulus elasticity (14 days) (MPa) | 2110.9 MPa | 381 | 1194.6 | 689.8 | 750 | 521.3 | 665.9 |
| Increase/decrease | - | -81.95 % | -43.41 % | -67.32 % | -64.47 % | -75.30 % | -68.45 % |
| Information | - | Downs | Downs | Downs | Downs | Downs | Downs |
| Modulus elasticity (28 days) (MPa) | 1147.4 | 792.1 | 3290 | 3050 | 2476.3 | 2170 | 1333.8 |
| Increase/decrease | - | -30.97 % | +186.74 % | +165.82 % | +115.82 % | +89.12 % | +16.25 % |
| Information | - | Downs | Ups | Ups | Ups | Ups | Ups |
| Stretch ($\varepsilon$) (14 days) | 0.0064 | 0.0158 | 0.007 | 0.0079 | 0.0076 | 0.008 | 0.0086 |
| Stretch ($\varepsilon$) (28 days) | 0.0177 | 0.0139 | 0.0031 | 0.002 | 0.0038 | 0.0037 | 0.0066 |
| Voltage ($\sigma$) (14 days) (MPa) | 13.51 | 6.02 | 8.90 | 5.45 | 5.70 | 4.50 | 5.76 |
| Voltage ($\sigma$) (28 days) (MPa) | 20.31 | 11.05 | 10.2 | 6.10 | 9.41 | 8.90 | 8.87 |

## IV. CONCLUSIONS

The present study evaluates and compares the elastic modulus of mortar modified with crumb rubber at variations of 10%, 15%, and 20% under two conditions: normal and heated at 150 °C:

- A comparison of the elastic modulus of normal mortar reveals a substantial increase in comparison with mortars with 10%, 15%, and 20% crumb rubber concentrations, both before and after heating at 14 days. This observation suggests that standard mortar contains high levels of stiffness and is less prone to fracture. Conversely, mortars including crumb rubber show higher elasticity and substantial deformation resistance.
- The incorporation of 10% crumb rubber into the mortar at 28 days before heating reveals a high degree of elasticity, exhibits enhanced deformation resistance, and improved flexural properties in comparison to the conventional mortar and other crumb rubber concentrations, both before and after heating at 150 °C.
- The elastic modulus of 10% crumb rubber mortar before heating exhibited a 30.97% decrease compared to the normal mortar. However, it demonstrated increased elasticity, higher energy absorption, and excellent deformation.

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## DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

## REFERENCES

[1] N. Andita *et al.*, "Elasticity in Daily Life: A Potential Topics in Learning Physics," *International Journal of Research and Community Empowerment*, vol. 2, no. 2, pp. 65–73, Aug. 2024, https://doi.org/10.58706/ijorce.v2n2.p65-73.

[2] D. Chen, J. Zou, L. Zhao, S. Xu, T. Xiang, and C. Liu, "Degradation of Dynamic Elastic Modulus of Concrete under Periodic Temperature-Humidity Action," *Materials*, vol. 13, no. 3, Jan. 2020, Art. no. 611, https://doi.org/10.3390/ma13030611.

[3] X. Feng, M. Fehler, D. Burns, S. Brown, and T. L. Szabo, "Effects of humidity and temperature on the non-linear elasticity of rocks," *Geophysical Journal International*, vol. 231, no. 3, pp. 1823–1832, Dec. 2022, https://doi.org/10.1093/gji/ggac292.

[4] G. Zhang, C. Li, H. Wei, M. Wang, Z. Yang, and Y. Gu, "Influence of Humidity on the Elastic Modulus and Axis Compressive Strength of Concrete in a Water Environment," *Materials*, vol. 13, no. 24, Jan. 2020, Art. no. 5696, https://doi.org/10.3390/ma13245696.

[5] T. T. Zhu, A. J. Bushby, and D. J. Dunstan, "Materials mechanical size effects: a review," *Materials Technology*, vol. 23, no. 4, pp. 193–209, Dec. 2008, https://doi.org/10.1179/175355508X376843.

[6] B. P. Murphy, P. Savage, P. E. McHugh, and D. F. Quinn, "The stress-strain behavior of coronary stent struts is size dependent," *Annals of*

*Biomedical Engineering*, vol. 31, no. 6, pp. 686–691, June 2003, https://doi.org/10.1114/1.1569268.

[7] Y. H. Zhao *et al.*, "Influence of specimen dimensions and strain measurement methods on tensile stress–strain curves," *Materials Science and Engineering: A*, vol. 525, no. 1, pp. 68–77, Nov. 2009, https://doi.org/10.1016/j.msea.2009.06.031.

[8] R. P. C. Driessen *et al.*, "Effect of temperature on the intrinsic flexibility of DNA and its interaction with architectural proteins," *Biochemistry*, vol. 53, no. 41, pp. 6430–6438, Oct. 2014, https://doi.org/10.1021/bi500344j.

[9] A. Karshikoff, L. Nilsson, and R. Ladenstein, "Rigidity versus flexibility: the dilemma of understanding protein thermal stability," *The FEBS Journal*, vol. 282, no. 20, pp. 3899–3917, 2015, https://doi.org/10.1111/febs.13343.

[10] X. Dai *et al.*, "Experimental investigation on flexible inorganic phase change material for thermal management performance improvement of lithium-ion battery," *Applied Thermal Engineering*, vol. 272, Aug. 2025, Art. no. 126358, https://doi.org/10.1016/j.applthermaleng.2025.126358.

[11] Q. Li *et al.*, "Flexible high-temperature dielectric materials from polymer nanocomposites," *Nature*, vol. 523, no. 7562, pp. 576–579, July 2015, https://doi.org/10.1038/nature14647.

[12] I. Alenezi, "Effects of Heat Treatment on the Corrosion Behavior of ASTM A-36 Steel," *Engineering, Technology & Applied Science Research*, vol. 10, no. 1, pp. 5320–5324, Feb. 2020, https://doi.org/10.48084/etasr.3326.

[13] K. Kalinowska-Wichrowska, E. Pawluczuk, M. Bołtryk, J. R. Jimenez, J. M. Fernandez-Rodriguez, and D. Suescum Morales, "The Performance of Concrete Made with Secondary Products—Recycled Coarse Aggregates, Recycled Cement Mortar, and Fly Ash–Slag Mix," *Materials*, vol. 15, no. 4, Jan. 2022, Art. no. 1438, https://doi.org/10.3390/ma15041438.

[14] J. Shang, J.-G. Dai, T.-J. Zhao, S.-Y. Guo, P. Zhang, and B. Mu, "Alternation of traditional cement mortars using fly ash-based geopolymer mortars modified by slag," *Journal of Cleaner Production*, vol. 203, pp. 746–756, Dec. 2018, https://doi.org/10.1016/j.jclepro.2018.08.255.

[15] M. L. Berndt, "Properties of sustainable concrete containing fly ash, slag and recycled concrete aggregate," *Construction and Building Materials*, vol. 23, no. 7, pp. 2606–2613, July 2009, https://doi.org/10.1016/j.conbuildmat.2009.02.011.

[16] G. Li *et al.*, "Fly Ash Application as Supplementary Cementitious Material: A Review," *Materials*, vol. 15, no. 7, Jan. 2022, Art. no. 2664, https://doi.org/10.3390/ma15072664.

[17] M. Nazeer, K. Kapoor, and S. P. Singh, "Strength, durability and microstructural investigations on pervious concrete made with fly ash and silica fume as supplementary cementitious materials," *Journal of Building Engineering*, vol. 69, June 2023, Art. no. 106275, https://doi.org/10.1016/j.jobe.2023.106275.

[18] L. A. Qureshi, B. Ali, and A. Ali, "Combined effects of supplementary cementitious materials (silica fume, GGBS, fly ash and rice husk ash) and steel fiber on the hardened properties of recycled aggregate concrete," *Construction and Building Materials*, vol. 263, Dec. 2020, Art. no. 120636, https://doi.org/10.1016/j.conbuildmat.2020.120636.

[19] K. L. Scrivener and R. J. Kirkpatrick, "Innovation in use and research on cementitious material," *Cement and Concrete Research*, vol. 38, no. 2, pp. 128–136, Feb. 2008, https://doi.org/10.1016/j.cemconres.2007.09.025.

[20] R. M. I. R. Susilorini *et al.*, "The Advantage of Natural Polymer Modified Mortar with Seaweed: Green Construction Material Innovation for Sustainable Concrete," *Procedia Engineering*, vol. 95, pp. 419–425, Jan. 2014, https://doi.org/10.1016/j.proeng.2014.12.201.

[21] A. M. Omer, "Energy, environment and sustainable development," *Renewable and Sustainable Energy Reviews*, vol. 12, no. 9, pp. 2265–2300, Dec. 2008, https://doi.org/10.1016/j.rser.2007.05.001.

[22] A. Almusaed, I. Yitmen, J. A. Myhren, and A. Almssad, "Assessing the Impact of Recycled Building Materials on Environmental Sustainability and Energy Efficiency: A Comprehensive Framework for Reducing Greenhouse Gas Emissions," *Buildings*, vol. 14, no. 6, June 2024, Art. no. 1566, https://doi.org/10.3390/buildings14061566.

[23] D. W. Dobson, A. Sourani, B. Sertyesilisik, and A. Tunstall, "Sustainable Construction: Analysis of Its Costs and Benefits," *American Journal of Civil Engineering and Architecture*, vol. 1, no. 2, pp. 32–38, Jan. 2013, https://doi.org/10.12691/ajcea-1-2-2.

[24] G. Salvalai, M. M. Sesana, P. Dell'Oro, and D. Brutti, "Open Innovation for the Construction Sector: Concept Overview and Test Bed Development to Boost Energy-Efficient Solutions," *Energies*, vol. 16, no. 14, Jan. 2023, Art. no. 5522, https://doi.org/10.3390/en16145522.

[25] J. Los Santos - Ortega, E. Fraile - García, and J. Ferreiro - Cabello, "Methodology for the environmental analysis of mortar doped with crumb rubber from end-of-life tires," *Construction and Building Materials*, vol. 399, Oct. 2023, Art. no. 132519, https://doi.org/10.1016/j.conbuildmat.2023.132519.

[26] S. Ren, X. Liu, P. Lin, H. Wang, W. Fan, and S. Erkens, "The continuous swelling-degradation behaviors and chemo-rheological properties of waste crumb rubber modified bitumen considering the effect of rubber size," *Construction and Building Materials*, vol. 307, Nov. 2021, Art. no. 124966, https://doi.org/10.1016/j.conbuildmat.2021.124966.

[27] Z. T. Abdullah, "Quantitative sustainability assessment of plant layouts for mechano-chemical remanufacturing of waste tires into rubber sheets with integrated pyrolysis-distillation," *Environmental Challenges*, vol. 15, Apr. 2024, Art. no. 100949, https://doi.org/10.1016/j.envc.2024.100949.

[28] E. El-Seidy *et al.*, "Mechanical and physical characteristics of alkali-activated mortars incorporated with recycled polyvinyl chloride and rubber aggregates," *Journal of Building Engineering*, vol. 60, Nov. 2022, Art. no. 105043, https://doi.org/10.1016/j.jobe.2022.105043.

[29] K. Hancharoen, P. Kamhangrittirong, and P. Suwanna, "Improvement of natural fiber cement composite for roofing applications through addition of waste tire rubber: An investigation of the physical, mechanical, thermal, and acoustic properties," *Cleaner Materials*, vol. 13, Sept. 2024, Art. no. 100265, https://doi.org/10.1016/j.clema.2024.100265.

[30] N. Habib, M. Saqib, T. Najeh, and Y. Gamil, "Eco-Transformation of construction: Harnessing machine learning and SHAP for crumb rubber concrete sustainability," *Heliyon*, vol. 10, no. 5, Mar. 2024, Art. no. e26927, https://doi.org/10.1016/j.heliyon.2024.e26927.

[31] P. Gill, P. Jangra, R. Roychand, M. Saberian, and J. Li, "Effects of various additives on the crumb rubber integrated geopolymer concrete," *Cleaner Materials*, vol. 8, June 2023, Art. no. 100181, https://doi.org/10.1016/j.clema.2023.100181.

[32] W.J. Song, W.G. Qiao, X.X. Yang, D.G. Lin, and Y.Z. Li, "Mechanical properties and constitutive equations of crumb rubber mortars," *Construction and Building Materials*, vol. 172, pp. 660–669, May 2018, https://doi.org/10.1016/j.conbuildmat.2018.03.263.