

Environmental Implications of Liquid Natural Rubber Latex as a Sustainable Additive in Concrete: Effects on Mechanical Performance and Water–Cement Interaction

Hani Purwanti*, Purwanto, Trias Widorini, Talitha Zhafira

Department of Civil Engineering, Universitas Semarang, Semarang, Central Java, 50196, Indonesia

*Correspondence: hanipurwanti@usm.ac.id

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ABSTRACT: Increasing demand for ecologically friendly construction materials has promoted the use of renewable additives in concrete systems. This study investigates the influence of liquid natural rubber latex on the mechanical properties and water–cement interaction of conventional concrete with a focus on the environmental impact. Concrete mixtures were made using 0%, 5%, 7.5%, and 10% by volume of latex. Compressive and flexural strength tests were performed at 28 days to evaluate structural performance. The results show that increasing the latex content consistently decreases mechanical characteristics. Compressive strength dropped by roughly 10%, 18% and 26% and flexural strength reduced by 8%, 14% and 20% with 5%, 7.5% and 10% latex additions accordingly. This behavior is related to the involvement of latex as an extra fluid phase which affects the effective water–cement ratio, modifies hydration and leads to increased porosity and weaker bonding within the concrete matrix. From an environmental perspective, natural rubber latex provides advantages as a renewable and biodegradable resource that can lessen dependence on synthetic admixtures. However, the decline in mechanical performance suggests potential trade-offs, including reduced durability and greater material demand over the service life. The results imply that the latex application in concrete should be carefully regulated or supplemented with stabilizing materials to attain the best results. In conclusion, this study emphasizes the necessity to reconcile environmental benefits and engineering needs in the development of bio-based construction materials, especially in tropical settings.

KEYWORDS: Bio-based additive; renewable resource; mechanical properties; hydration behavior; sustainable materials

1. Introduction

The rapid expansion of infrastructure development in tropical countries has led to a substantial increase in the demand for construction materials, particularly concrete. Although concrete remains one of the most widely used materials because of its availability, durability, and

structural performance, its production has been closely associated with environmental concerns such as high energy consumption, resource depletion, and environmental degradation [1, 2]. In recent years, increasing attention has been directed toward the development of sustainable and environmentally friendly construction materials to reduce the ecological footprint of the construction sector. One potential approach has been the utilization of bio-based and renewable resources as partial replacements or additives in concrete. Natural rubber latex is widely available in tropical countries such as Indonesia and has been considered an environmentally friendly material because it is renewable and biodegradable. The incorporation of such materials into concrete not only promoted the sustainable use of resources but also aligned with the global trend toward green construction [3, 4]. Moreover, the use of natural materials may reduce dependence on synthetic chemical admixtures, which are often associated with environmental hazards during manufacturing and disposal [5].

Despite its environmental advantages, the use of liquid natural rubber latex in concrete posed significant challenges regarding its interaction with the cementitious system and its potential effects on material performance and environmental behavior. In particular, the inclusion of latex may influence the water–cement ratio, hydration process, and pore structure of concrete, which subsequently affect its mechanical properties and durability. These mechanisms are closely related to hydration chemistry and microstructural development in cement-based materials [9, 10], as well as the influence of polymeric molecules on cement systems [11]. Such modifications are important because they may indirectly affect the long-term environmental performance of concrete structures, including resistance to degradation and reduction of material waste. Previous studies have shown that rubber-based compounds can improve certain properties of concrete, particularly flexibility and crack resistance [6, 7]. At the same time, the development of bio-based construction materials has attracted increasing attention as part of sustainable material innovation [8]. However, data regarding the use of liquid latex as an additive remained limited and often inconsistent, especially concerning its effects on compressive and flexural strength. Furthermore, most previous studies primarily focused on mechanical behavior, while limited attention was given to the environmental implications of incorporating natural rubber latex into concrete systems. Although considerable studies have investigated rubberized concrete utilizing crumb rubber or rubber fibers, only limited research has examined the use of liquid natural rubber latex as a fresh-phase additive that directly interacts with the water–cement system. Unlike solid rubber inclusions, liquid latex has the potential to simultaneously modify hydration kinetics and effective water content, presenting a novel mechanism of performance modification that remains insufficiently understood. Moreover, most existing studies focused primarily on mechanical performance, whereas the environmental implications of liquid latex incorporation in concrete, particularly in relation to durability-related sustainability, have not been extensively investigated.

The present study aimed to evaluate the environmental implications of using liquid natural rubber latex as a sustainable additive in conventional concrete, with particular emphasis on its interaction with the water–cement system and its effects on compressive and flexural strength. The results indicated that natural rubber latex possesses potential as an eco-friendly material. However, the addition of natural rubber latex reduced mechanical performance because of the increase in effective water content. These findings were comparable with previous studies on the mechanical behavior of modified concrete systems [12] and highlighted the importance of optimization strategies to balance environmental benefits and structural

performance in the development of eco-friendly concrete materials. Thus, this study contributed to the literature by: (i) exploring liquid natural rubber latex as a bio-based fluid additive in concrete, (ii) characterizing its dual role in mechanical performance and water–cement interaction, and (iii) providing an integrated discussion of its environmental implications based on performance–durability relationships. Unlike earlier investigations that focused on solid rubber particles or crumb rubber, this study specifically examined liquid natural rubber latex as a fresh-phase modifier that directly altered the effective water–cement ratio and hydration kinetics rather than functioning as an inert filler. This provided unique mechanistic insight into the influence of polymeric liquid additives on mechanical performance and durability-related sustainability metrics.

2. Materials and Methods

2.1. Study area and experimental framework.

The present study employed a laboratory-based experimental methodology to evaluate the environmental implications of incorporating liquid natural rubber latex as a bio-based additive in concrete. Concrete specimens were produced at a ready-mix plant in Demak, Indonesia, while mechanical and physical testing were conducted at the Laboratory of Materials and Structures, Universitas Semarang. The experimental framework was designed to investigate the interaction between latex, as a renewable and biodegradable material, and the cementitious system, particularly its influence on water–cement behavior and indirect environmental impacts such as material durability and resource efficiency.

2.2. Materials and environmental considerations.

The materials utilized in this study included Portland cement, fine aggregate (sand), coarse aggregate (crushed stone), water, and liquid natural rubber latex. The latex used was a natural polymer obtained from renewable resources and was considered more environmentally friendly than synthetic admixtures. All materials were stored under controlled conditions prior to mixing to prevent environmental contamination and material degradation. Particular attention was given to latex handling to ensure consistent physical properties because the moisture content of the latex could affect the effective water–cement ratio and subsequently influence both the mechanical and environmental performance of the concrete. The selection and performance considerations of these materials were consistent with previous studies on concrete material behavior and structural performance [13]. The liquid natural rubber latex employed in this study was supplied as a commercially available natural polymer emulsion. According to the manufacturer, the latex had a solid content of approximately 60%, a pH of 9.5–10.5, and a viscosity of 50–200 cP at room temperature (25°C). These properties were important because they influenced effective water–cement interaction and the dispersion behavior of polymer particles within the cement matrix. The latex was stored under controlled conditions prior to use to maintain stability and prevent phase separation.

2.3. Material characterization.

The aggregates were characterized according to ASTM standards to ensure compliance with concrete production requirements. The tests conducted included grading analysis, specific

gravity, and water absorption capacity. The Portland cement utilized in this study was assumed to comply with standard specifications. Liquid natural rubber latex was characterized based on its density to determine its contribution to the total mix volume and its interaction with mixing water. The standardized testing procedures and evaluation methods employed in this study were consistent with those commonly used in the field of concrete material characterization [14, 15].

2.4. Specimen design and mix proportions.

The experimental program was designed using cylindrical and beam specimens to evaluate the compressive and flexural behavior of concrete containing liquid natural rubber latex. A total of 40 specimens were prepared, consisting of 20 cylindrical specimens for compressive strength testing and 20 beam specimens for flexural strength testing. The distribution of the cylindrical specimens is presented in Table 1, while the beam specimen configuration is summarized in Table 2. The concrete mix design targeted a compressive strength of K200, and the detailed mix proportions for each variation are presented in Table 3. The latex content was incorporated as a percentage of the total concrete volume, and its influence on the effective water content was considered as part of the environmental interaction analysis. The link between water content, porosity and the compressive strength is a key component in influencing the performance of concrete [16].

Table 1. Number of cylindrical concrete specimens.

Mixture (Latex Content)	Diameter (cm)	Height (cm)	Number of Specimens
0% latex	15	30	5
5% latex	15	30	5
7.5% latex	15	30	5
10% latex	15	30	5
Total			20

Table 2. Number of beam concrete specimens.

Mixture (Latex Content)	Span Length (cm)	Width (cm)	Height (cm)	Number of Specimens
0% latex	60	15	15	5
5% latex	60	15	15	5
7.5% latex	60	15	15	5
10% latex	60	15	15	5
Total				20

Table 3. Concrete mix design proportions.

Material	0%	5%	7.50%	10%	Unit
Cement	286	286	286	286	kg/m ³
Sand	1053	1053	1053	1053	kg/m ³
Crushed stone	905	905	905	905	kg/m ³
Rubber latex	0	14.3	21.4	28.6	kg/m ³
Water	185	185	185	185	l/m ³

2.5. Specimen preparation procedure.

Concrete mixing was carried out using a mechanical mixer to ensure homogeneity. The mixing process involved dry blending of cement and aggregates, followed by the gradual addition of water and liquid natural rubber latex under continuous mixing to achieve uniform dispersion. Workability was assessed using slump tests conducted immediately after mixing, as this parameter is critical in determining water demand and potential environmental performance implications. The fresh concrete was then cast into cylindrical and beam molds, and

compaction was applied to remove entrapped air and ensure proper densification. The interaction between polymer-based additives and cement hydration during mixing has been extensively reported in previous studies [17, 18].

2.6. Curing method and environmental relevance.

All specimens were water-cured by immersion for 28 days after initial setting. This curing method was selected to ensure adequate moisture availability for continued hydration and to simulate moisture-rich environmental exposure conditions. Proper curing is essential for strength development and for minimizing microcracking that may increase permeability and reduce long-term durability. These processes are closely associated with pore structure evolution and microstructural development in cementitious materials [19].

2.7. Mechanical testing.

Compressive strength tests were performed on cylindrical specimens at 7, 14, and 28 days using a compression testing machine. Flexural strength tests were conducted on beam specimens using a hydraulic concrete beam testing machine under a two-point loading configuration. These tests enabled evaluation of the structural performance of latex-modified concrete, which is directly related to service life, maintenance demand, and overall environmental sustainability. The mechanical behavior of rubberized and modified concrete has been widely documented in previous studies [20].

2.8. Data collection and analysis.

Experimental results were collected and analyzed to obtain the average compressive and flexural strength values for each mix variation. The percentage change relative to the control mixture (0% latex) was also calculated to evaluate performance differences. In addition to mechanical performance, indirect environmental implications of latex incorporation were assessed using performance-based indicators, particularly strength retention relative to the control mix and qualitative durability inference based on established relationships between compressive strength, porosity, and permeability. This approach provides insight into sustainability-related performance without requiring full life cycle assessment. Statistical analysis was conducted using one-way analysis of variance (ANOVA) at a 95% confidence level ($p < 0.05$) to determine whether variations in liquid natural rubber latex content (0%, 5%, 7.5%, and 10%) produced statistically significant differences in mechanical properties. Each mix condition was tested using five replicate specimens ($n = 5$), and results were reported as mean \pm standard deviation (mean \pm SD) to describe variability and reliability. All statistical analyses were performed using standard statistical software, and significance was determined at $p < 0.05$.

3. Results and Discussion

3.1. Compressive strength and environmental implications.

Table 4 presented the compressive strength results of concrete with different proportions of liquid natural rubber latex. The compressive strength of the mixtures decreased consistently with the addition of latex compared to the control mixture (0% latex), as shown in Table 4. The

average compressive strength of the control mix was 284.05 kg/cm². It decreased to 256.34 kg/cm², 233.24 kg/cm², and 210.03 kg/cm² for 5%, 7.5%, and 10% latex content, respectively, corresponding to reductions of approximately 10%, 18%, and 26%. The reduction in compressive strength can be attributed to the increasing incorporation of latex, which likely introduced additional voids and reduced the overall compactness of the concrete matrix. As shown in Table 4, both the applied load and resulting compressive strength progressively declined with higher latex content, indicating a weakening of load-bearing capacity. The density values also showed slight fluctuations but did not increase sufficiently to compensate for strength loss. This suggests that latex acted more as a modifying agent than a reinforcing component in the hardened concrete structure.

Table 4. Compressive strength test results of concrete.

Latex Content (%)	Specimen	Age (days)	Weight (kg)	Density (g/cm ³)	Load (kN)	Compressive Strength (kg/cm ²)
0	1	28	12.512	2.359	490	282.89
	2	28	12.62	2.38	480	277.12
	3	28	12.66	2.387	480	277.12
	4	28	12.38	2.334	510	294.44
	5	28	12.61	2.378	500	288.67
Average						284.05
5	1	28	12.51	2.359	450	259.8
	2	28	12.62	2.38	440	254.03
	3	28	12.66	2.387	460	265.57
	4	28	12.38	2.334	440	254.03
	5	28	12.61	2.378	430	248.25
Average						256.34
7.5	1	28	12.51	2.359	400	230.93
	2	28	12.62	2.38	420	242.48
	3	28	12.66	2.387	410	236.71
	4	28	12.38	2.334	400	230.93
	5	28	12.61	2.378	390	225.16
Average						233.24
10	1	28	12.51	2.359	375	216.5
	2	28	12.62	2.38	360	207.84
	3	28	12.66	2.387	360	207.84
	4	28	12.38	2.334	359	207.26
	5	28	12.61	2.378	365	210.73
Average						210.03

The variation of compressive strength for individual specimens is illustrated in Figure 1, which shows the distribution of compressive strength values for each latex content level (0%, 5%, 7.5%, and 10%). It was observed that the results within each group were relatively consistent, with only slight variations reflected in the standard deviation values (5.40–6.60). The control mixture (0% latex) exhibited the highest compressive strength, while a gradual reduction in strength was observed as latex content increased.

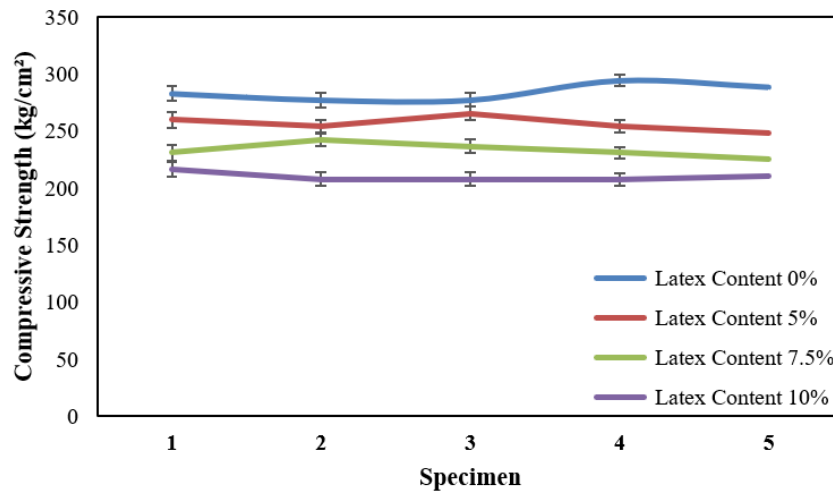


Figure 1. Compressive strength distribution of concrete specimens with varying liquid natural rubber latex content (mean ± standard deviation).

The average compressive strength and standard deviation for each mixture are shown in Figure 2. The compressive strength decreased from 284.05 kg/cm² (0% latex) to 256.34 kg/cm² (5%), 233.24 kg/cm² (7.5%), and 210.03 kg/cm² (10%). The trend indicated an almost linear decrease in compressive strength with increasing latex content, suggesting that higher latex proportions reduced load-bearing capacity due to changes in the water–cement interaction and increased porosity. The reduction in compressive strength may be attributed to the role of liquid rubber latex as an additional fluid phase within the concrete matrix. This condition effectively increased the water–cement ratio, which is known to weaken bonding between cement paste and aggregates. The compressive strength results were further analyzed statistically to determine the significance of differences among mixtures. Data were reported as mean ± standard deviation (mean ± SD). One-way ANOVA at a 95% confidence level ($p < 0.05$) indicated significant differences in compressive strength among the control and latex-modified concrete mixtures. This confirmed that liquid natural rubber latex content had a significant effect on compressive strength development.

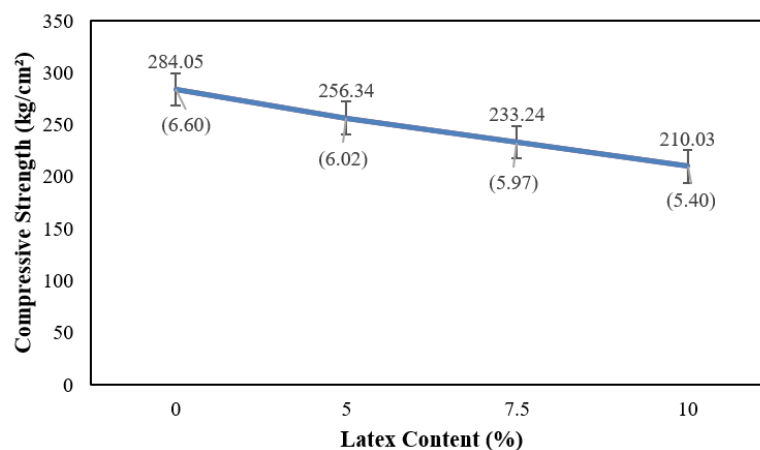


Figure 2. Average compressive strength of concrete as a function of liquid natural rubber latex content (mean ± standard deviation).

The compressive strength decreased almost linearly with increasing latex content; however, a slightly higher reduction rate was observed between 7.5% and 10%, suggesting a threshold effect in which excessive latex significantly disrupted cement hydration continuity

and internal bonding structure. This nonlinear behavior was attributed to increasing disruption of the hydration network and the formation of an additional fluid phase induced by liquid latex. The presence of this phase increased capillary porosity, weakened the interfacial transition zone (ITZ), and reduced the density of the hardened cement matrix, particularly at higher dosages. From a microstructural perspective, increased porosity and reduced density of hardened concrete were observed. These findings were consistent with previous studies on rubberized concrete behavior [21, 22] and the relationship between porosity and compressive strength [23, 25, 26]. In addition, microstructural alterations and internal degradation mechanisms were reported to significantly influence concrete performance [24, 18, 20]. From an environmental perspective, this behavior represented an important trade-off. Natural rubber latex is renewable and biodegradable and may reduce dependence on synthetic chemical admixtures. However, reductions in compressive strength may shorten service life or increase material demand to achieve equivalent structural performance. This implies that although latex contributes positively to material sustainability, its mechanical limitations may indirectly increase environmental burden through higher resource consumption and maintenance needs. Therefore, optimization of latex dosage is necessary to balance environmental benefits and structural efficiency.

3.2. Flexural strength and material sustainability.

Table 5 presents the flexural strength data for all mixes. Similar to the compressive strength results, the flexural performance decreased gradually with the addition of liquid natural rubber latex, indicating a consistent reduction in the ability of concrete to resist tensile stresses under bending loads. The average flexural strength values were 47.47 kg/cm² for the control mix (0% latex), followed by 43.73 kg/cm² (5% latex), 40.80 kg/cm² (7.5% latex), and 37.87 kg/cm² (10% latex). This corresponds to overall reductions of approximately 8%, 14%, and 20% relative to the control mixture.

Table 5. Flexural strength test results of concrete

Latex Content (%)	Specimen	Age (days)	Weight (kg)	Density (g/cm ³)	Load (kN)	Span (cm)	Beam Size (cm)	Flexural Strength (kg/cm ²)
0	1	28	27.4	2.436	36	45	15×15	48
	2	28	27.43	2.438	36	45	15×15	48
	3	28	27.21	2.419	34	45	15×15	45.33
	4	28	27.33	2.429	35	45	15×15	46.67
	5	28	27.12	2.411	37	45	15×15	49.33
Average								47.47
5	1	28	27.33	2.429	33	45	15×15	44
	2	28	27.27	2.424	32	45	15×15	42.67
	3	28	27.34	2.43	32	45	15×15	42.67
	4	28	27.31	2.428	34	45	15×15	45.33
	5	28	27.38	2.434	33	45	15×15	44
Average								43.73
7.5	1	28	27.44	2.439	32	45	15×15	42.67
	2	28	27.22	2.42	32	45	15×15	42.67
	3	28	27.62	2.455	30	45	15×15	40
	4	28	27.23	2.42	30	45	15×15	40
	5	28	27.43	2.438	29	45	15×15	38.67
Average								40.8
10	1	28	27.39	2.435	27	45	15×15	36
	2	28	27.32	2.428	30	45	15×15	40
	3	28	27.83	2.474	28	45	15×15	37.33
	4	28	27.44	2.439	28	45	15×15	37.33
	5	28	27.28	2.425	29	45	15×15	38.67
Average								37.87

From Table 5, it can be observed that individual specimen results within each mixture group show relatively small variations, indicating good consistency in specimen preparation and testing procedures. The standard deviation within each group remains low, suggesting that the observed trends are reliable and not influenced by significant experimental scatter. The control specimens consistently exhibited higher flexural strength values compared to latex-modified mixes, confirming that the inclusion of liquid latex progressively weakened the tensile resistance of the concrete matrix. The reduction in flexural strength with increasing latex content can be attributed to the presence of an additional fluid phase introduced by the latex, which disrupts the cement–aggregate bond and increases internal void formation. This weakens the interfacial transition zone (ITZ) and reduces the material’s ability to resist crack initiation and propagation under bending stress. Consequently, although liquid natural rubber latex may improve certain workability and sustainability aspects, its incorporation leads to a measurable decline in flexural performance, as clearly demonstrated in Table 5.

Figure 3 shows the distribution of flexural strength values for individual beam specimens across all mixtures with varying liquid natural rubber latex contents (0%, 5%, 7.5%, and 10%). The figure illustrates that the flexural strength values are relatively consistent within each mixture group, indicating good repeatability of the experimental results. This consistency is supported by the low standard deviation values (ranging from 1.12 to 1.38), which suggest minimal variability among replicate specimens and reliable specimen preparation and testing procedures. From the distribution pattern, it is clearly observed that the control mixture (0% latex) consistently achieves the highest flexural strength values, ranging from 45.33 to 49.33 kg/cm². In contrast, all latex-modified mixes exhibit lower and progressively decreasing flexural strength values as the latex content increases. This downward shift in the distribution indicates a systematic reduction in bending resistance with increasing latex dosage.

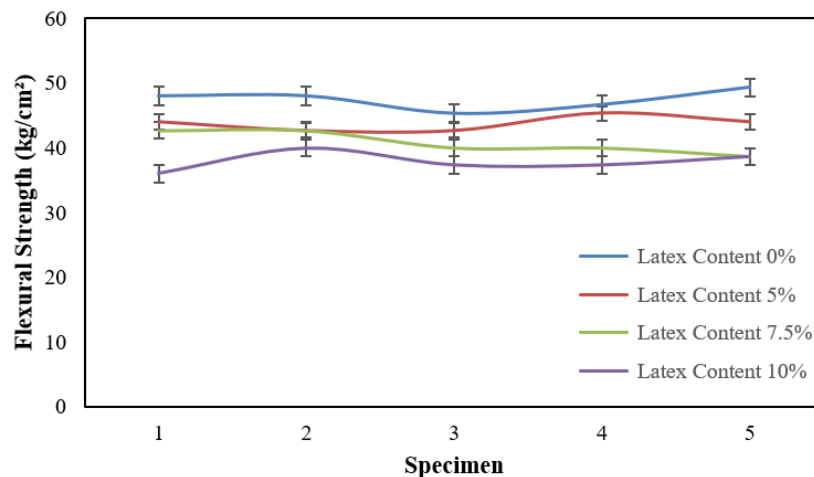


Figure 3. Flexural strength distribution of concrete specimens with varying liquid natural rubber latex content (mean ± standard deviation).

Meanwhile, the average flexural strength and standard deviation of each latex content level is shown in Figure 4. The result clearly indicates a constant decreasing trend of flexural strength with increase in latex dose from 47.47 kg/cm² at 0% latex to 43.73 kg/cm² at 5%, 40.80 kg/cm² at 7.5% and 37.87 kg/cm² at 10%. The downward trend suggests that the flexural capacity of concrete is gradually reduced with the addition of liquid natural rubber latex, which is related to the deterioration of cement–aggregate bonding and the increase in the creation of internal voids that decrease the resistance to the tensile stress under flexural loads.

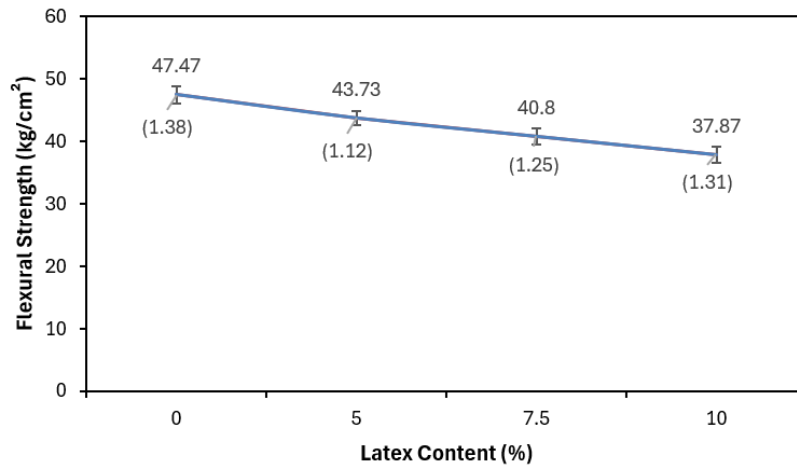


Figure 4. Average flexural strength of concrete as a function of liquid natural rubber latex content (mean \pm standard deviation).

The drop in flexural strength demonstrated the effect of latex addition on the tensile behavior of concrete, likely due to the deterioration of interfacial adhesion and the formation of internal voids. These effects are consistent with studies on the influence of additives and supplementary materials on tensile behavior [25], although they reduced the material's ability to resist bending loads. The obtained flexural strength results were statistically analyzed using a one-way ANOVA at a 95% confidence level ($p < 0.05$). The results showed that there were significant statistical differences among all mixes. Flexural strength data were presented as mean \pm standard deviation to account for variability between specimens. Flexural strength decreased with increasing latex content, similar to the trend observed for compressive strength. This reduction pattern indicated that the addition of latex had a more pronounced effect on tensile resistance, as evidenced by the greater reduction in flexural performance compared to compressive strength. This phenomenon could be attributed to weak interfacial bonding and increased formation of internal voids, which reduced the ability of the concrete matrix to withstand tensile stresses. The loss of cement–aggregate adhesion was particularly critical under bending loads, leading to earlier crack initiation and propagation.

Flexural strength is closely related to cracking resistance and durability in terms of environmental performance. Lower flexural strength may lead to earlier fracture formation, which in turn may increase permeability and the ingress of water and aggressive chemicals. This condition can accelerate degradation processes, especially in environments exposed to moisture and contaminants, as documented in studies on permeability and durability of concrete [26]. Therefore, although natural rubber latex is an environmentally friendly biodegradable material, its effects on durability-related properties must be carefully evaluated. Reduced durability may result in more frequent maintenance, repair, or replacement, which can ultimately increase the environmental impact of construction. These issues have been addressed in previous studies through the use of alternative and more eco-efficient concrete materials [27, 28].

3.3. Environmental trade-off and broader implications.

The combined results of compressive and flexural strength indicated a clear trend: increasing latex content reduced mechanical performance. However, these findings should not be interpreted purely from a structural perspective but also within a broader environmental

context. The results showed a clear trade-off between environmental benefits and mechanical performance. The advantages of natural rubber latex included its renewability and biodegradability, as well as its local availability in tropical regions and its potential to reduce reliance on synthetic chemical admixtures. However, its inclusion introduced an additional fluid phase, increasing the effective water–cement ratio and consequently leading to higher porosity, lower strength, and reduced durability potential. These mechanisms have been widely linked to accelerated permeability and degradation processes in cement-based materials, which can eventually result in increased material consumption over the service life of structures. This study demonstrated a fundamental trade-off between structural performance and material sustainability. Bio-based additives such as latex promote environmentally friendly construction; however, their use needs to be optimized to avoid detrimental effects on long-term material efficiency. Previous studies have examined efforts to improve the environmental performance of cement-based materials [29, 30], including strategies to reduce the environmental impact of concrete structures [31].

One of the major challenges in the development of green construction materials is the balance between sustainability and mechanical performance [32]. Moreover, the use of waste-derived and alternative materials has been suggested as a potential approach to improve eco-efficiency [33], although long-term durability remains a major concern in concrete construction [34]. In practice, the results imply that liquid rubber latex cannot be used as a direct replacement without modification. Instead, it may be more effective when used in combination with other stabilizing materials or in controlled proportions to achieve a balance between environmental benefits and engineering requirements. The present study results were compared with previous studies on rubberized and polymer-modified concrete in Table 6. The comparison highlights variations in material type, dosage range, and observed trends in mechanical performance, providing a broader perspective on the role of liquid natural rubber latex in cement-based systems.

Table 6. Comparison with previous studies.

Study	Type of Rubber	Content (%)	Strength Effect	Key Finding
This study	Liquid natural rubber latex	5–10	↓ 10–26% compressive	Fluid phase increases porosity
[21]	Rubber particles	5–15	Moderate strength reduction	Improved ductility
[22]	Crumb rubber	5–20	Strength decrease	Durability concerns
[23]	Rubberized concrete	5–15	Porosity–strength relation	Linear reduction trend
[24]	Rubber composite concrete	5–20	Microstructure degradation	ITZ weakening effect

A limitation of this study was the absence of direct durability testing, such as water absorption, sorptivity, or chloride penetration. Therefore, durability-related conclusions were inferred indirectly based on established relationships between compressive strength, porosity, and permeability reported in previous studies.

4. Conclusions

The incorporation of liquid natural rubber latex into concrete demonstrates that bio-based materials can significantly alter the internal physicochemical balance of cementitious systems, particularly by modifying the effective water–cement interaction. This phenomenon implies that, in addition to functioning as an additive, natural latex acts as a process-modulating agent that influences hydration and microstructural development. From an environmental

perspective, the use of natural rubber latex offers the opportunity to utilize renewable and biodegradable resources and reduce dependence on synthetic construction materials. However, the results show that material sustainability cannot be evaluated solely based on the origin of the resource. The influence of these materials on structural performance is a critical factor in determining their overall environmental viability. The study highlights the need for a holistic approach to sustainable material development, in which environmental benefits are integrated with long-term performance considerations to avoid unintended environmental trade-offs. Therefore, the use of bio-based additives in construction materials must be carefully optimized to ensure that improvements in environmental friendliness do not compromise structural efficiency and life-cycle sustainability. Future studies should focus on optimizing latex dosage through hybrid mix designs incorporating supplementary materials such as fly ash and silica fume, alongside detailed microstructural analysis to better understand hydration mechanisms and improve durability performance. Natural rubber latex, although not assessed through a full life cycle evaluation in this study, may offer potential reductions in embodied carbon compared to synthetic polymer admixtures due to its renewable origin and lower processing intensity. However, any environmental benefit must be balanced against potential increases in cement demand resulting from reduced mechanical performance.

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Author Contribution

Hani Purwanti: Conceptualization, methodology, supervision, writing – original draft preparation. Trias Widorini: Investigation, data curation, formal analysis, writing – review and editing. Talitha Zhafira: Experimental work, data collection, visualization, writing – supporting draft. All authors have read and approved the final version of the manuscript.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request. Due to the nature of laboratory-based experimental data, no publicly accessible repository has been used. All data are properly documented and can be shared for the purpose of verification and reproducibility of the results.

Competing Interest

No conflict of interest was reported by all authors.

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