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RESEARCH ARTICLE

Key Mechanical and Durability Characteristics of Concrete Admixed with Natural Rubber Latex and Sisal Fibre

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Abstract

Objectives: Significant infrastructure projects may require the use of high-performance concrete that possesses specific characteristics, including exceptional flexural strength, hardness, impact resistance and long-lasting durability. Polymer modified concrete is such type of concrete which improves the flexural strength and serviceability requirement of concrete buildings. **Methods:** The purpose of this study is to determine whether Natural Rubber Latex (NRL), a natural polymer, can replace synthetic latex and enhance the performance properties of concrete. Concrete is enhanced by the inclusion of natural rubber latex, which contributes a dry rubber content ranging from 0.5% to 1.5% of the weight of cement in the mixed composition. This study examines and compares the characteristics of latex modified concrete with sisal fibre-reinforced concrete with a constant sisal fibre content of 0.3%. It also investigates the combined effect of fibre and latex in concrete. **Findings:** The findings demonstrated a substantial enhancement in the ability of concrete to absorb energy (up to 166%) under impact loading. Additionally, the modification of concrete using latex resulted in an improvement in flexural strength of up to 39%. The decreased permeability of chloride ions and reduced water absorption in latex treated concrete are clear indications of its exceptional durability. **Novelty:** Polymer modified concrete using NRL is the next generation concrete and the sisal fibre incorporation in it is a relatively a novel approach in the field of concrete technology. It encourages the advancement of eco-friendly technology in the construction industry.

Keywords: Sisal Fibre; Impact resistance; Chloride permeability; Natural rubber latex; Water absorption

1 Introduction

High-performance concrete is a type of concrete that exhibits superior performance and durability compared to traditional concrete. The major applications of HPC includes, High-Rise Buildings, Bridges, Infrastructure, Marine Structures, Precast Concrete, Nuclear Containment, Hydroelectric Dams, High-Speed Rail etc. To enhance the life cycle performance and extend the lifespan of concrete pavements and structures, preventive measures must be implemented. Concrete is enhanced in specific applications by the addition of latex-based polymeric materials to enhance its resilience and durability[1–3]. The application of specific synthetic rubber latex for special requirements in major infrastructure projects is generally acknowledged. However, because to the increasing focus on sustainability and the concepts of the circular economy, it is necessary to utilize bio-based and alternative materials like Natural Rubber Latex (NRL) instead of synthetic rubber latex, which depends on non-renewable energy sources[4]. *Hevea brasiliensis* tree yields a milky substance known as natural rubber latex[5]. Field latex is a dispersion of rubber particles in a watery solution. The usual practice is to condense it in order to obtain a latex concentrate with a rubber content of 60%[6]. The primary nations that manufacture natural rubber are predominantly located in Southeast Asia, encompassing Thailand, Vietnam, Sri Lanka, India, Indonesia, and China. India ranks as the fourth largest global producer of natural rubber. Figure 1 displays the yearly output of natural rubber latex in India during the past seven years.

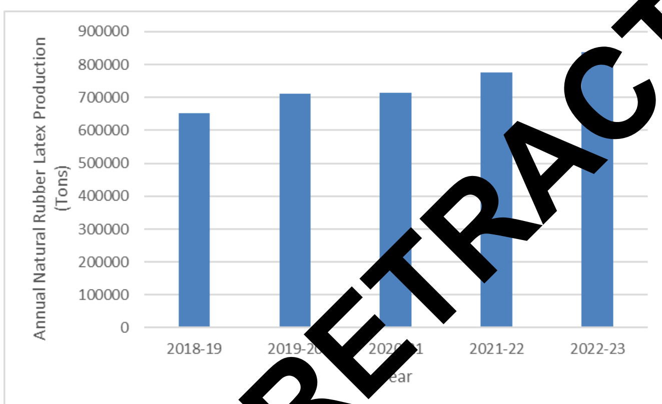

Fig 1. Annual natural rubber latex production in India

Utilizing natural rubber latex can enhance the resilience and malleability of concrete[7]. It enhances the cohesion between the aggregates and the cement matrix. Natural rubber possesses distinctive characteristics, like its elevated tensile strength, exceptional vibration-dampening qualities, and resistance to wear, which render it a superior option compared to synthetic rubber[8]. Due to its great value in terms of durability and reliability, this material is essential in the construction and automobile industries[7,9]. The mechanical strength of latex modified concrete is developed by the combined processes of cement hydration and latex film production. The presence of latex within the micropores of concrete improves the strength of the cementitious system that has been treated with latex. Latex is cured within the cement matrix to form a uniform and pliable film, similar to a nano-reinforced substance. This film enhances the flexural strength of the concrete. Previous researches have confirmed that the presence of latex causes a delay in the hydration of cement, resulting in the creation of thick films around the cement matrixes[7]. Excessive air entrainment in latex concrete might result in decreased strength and durability. Excessive air content can adversely affect the consistency and workability of latex concrete, making it challenging to handle and install. Excessive air entrainment can impede the correct adhesion of latex concrete to surfaces. The presence of air entrainment in latex concrete can lead to defects and abnormalities that have the ability to impact both the visual appearance and performance of the final product[10]. The incorporation of latex, in conjunction with surfactants, leads to enhancements in the compressive strength, water resistance, heat resistance, and pore-filling capabilities of the soft latex film[11]. Nhieu et al.[12] used NRL concrete in pavement base materials and found that it is well performed than conventional concrete.

Researchers are exploring natural fibres as a potential solution to enhance the durability and strength of concrete. Typically, natural fibres are obtained from botanical sources. They possess distinctive attributes such as their low density, wide accessibility, and comparatively affordable price. A comprehensive investigation was conducted on plant-based natural fibres, including flax, jute, cotton, and sisal[13–16]. One notable drawback is their susceptibility to moisture, particularly in the case of plant-derived fibres like cotton and sisal, which can experience a decrease in strength when exposed to moisture. Sisal stands out from other fibres due to its exceptional mechanical properties, renewable nature, and vast availability. From the literature, it is seen that structural concrete have been developed by using NRL. Limited standard researches are available in the area of fibre reinforced NRL concrete. Moreover, the combined use of NRL and sisal fibre in concrete is scanty. Hence, this study investigates the influence of integrating natural rubber latex into concrete on its compressive and flexural strength, energy absorption capacity under impact loading, resistance to abrasion, permeability to chloride ions, and water absorption. It also compares these effects with those of sisal fibre-reinforced NRL concrete.

2 Methodology

2.1 Materials

This study employed Ordinary Portland cement with a grade of 53 and Class F fly ash as binders. Table 1 presents the characteristic attributes of cement and fly ash. The construction employed a coarse aggregate with a maximum diameter of 20 mm, possessing a specific gravity of 2.74. In addition, a fine aggregate classified as zone II and having a specific gravity of 2.7 was used. A solution of natural rubber latex with a rubber content of 60.01% was used. Figure 2 **(a)** and **(b)** shows the Natural Rubber latex and sisal fibre that was utilized in this study respectively. Tables 2, 3 and 4 provide the specific physical characteristics of latex, sisal fiber, and defoamer, respectively.

(a) **(b)**

Fig 2. (a) Natural rubber latex, (b) Sisal fibre

The natural rubber latex was added to the cement at percentages of 0.5%, 1%, 1.5%, and 2% by weight of dry rubber content. The volume proportion of sisal fibre used was 0.3%. The amount of fibre was chosen based on the optimal dosage that resulted in the highest levels of compressive and flexural strength. In order to preserve the desired water-binder (w/b) ratio of the concrete mixtures, the water content in the latex was decreased. In this investigation, a superplasticizer based on polycarboxylate ether was utilized to ensure that the slump value of the concrete remained within the range of 50 mm to 75 mm. Due to the fact that the slump achieved for concrete modified with 2 percent NRL was below the permitted threshold, the maximum amount of latex that could be added was restricted to 2 percent.

Table 1. Properties of Cement and Fly ash

Chemical Properties (%)		
Oxides	**Cement**	**Fly ash**
Ca O	55.90	0.710
SiO_2	26.27	58.97
Al_2O_3	7.967	35.03
Fe_2O_3	3.040	3.022
MgO	2.497	0.977
SO_3	3.561	0.123
K_2O	0.547	0.531
Physical Properties		
Standard Consistency (%)	29.5	-
Setting Time Initial (min) Final (min)	120 210	-
Specific gravity	3.15	2.78

Table 2. Physical properties of concentrated natural rubber latex

Dry rubber (%)	Solids (%)	Ammonia (%)	Non-Rubber (%)	Volatile Fatty Acid (%)	pH	Sp. Grav.	Colour
59.91	62.01	0.80	1.41	0.023	9.4	0.951	White

Table 3. Properties of Sisal Fibre

L (mm)	Dia. (mm)	Aspect ratio	Density (g/cc)	Elastic Modulus (GPa)	Tensile Strength (MPa)
30	0.2-0.3	100-150	1.45	15-16	500-600

Table 4. Properties of defoamer

Solids (%)	Viscosity (cps)	pH	Sp. Grav.	Solubility	Colour
99.41	470	8.4	0.88	Water Soluble	White

2.2 Testing Scheme and Research Plan

The concrete mixtures proportions used for both normal concrete and modified concrete in this investigation are provided in Table 5. The water-to-binder (w/b) ratio for all the mixtures was consistently set at 0.4.

Table 5. Concrete mix proportion

Mixture ID	Cement(kg/m^3)	Fly ash(kg/m^3)	Fine Aggregate(kg/m^3)	Coarse Aggregate(kg/m^3)	NRL (%) by weight of cement	Sisal fibre (% by vol.)
Conventional Concrete (C)	355	89	611	1147	0	0
C-L 0.5	355	89	611	1147	0.5	0
C-L 1.0	355	89	611	1147	1	0
C-L 1.5	355	89	611	1147	1.5	0
S-C	355	89	611	1147	0	0.3
S-C-L 0.5	355	89	611	1147	0.5	0.3
S-C-L 1.0	355	89	611	1147	1	0.3
S-C-L 1.5	355	89	611	1147	1.5	0.3

C-L Concrete with Rubber Latex; **S-C** - Concrete with 0.3% Sisal fibre; **S-C-L** - Concrete with 0.3% Sisal fibre and Rubber Latex

A compressive strength test was conducted on a 150 mm size cube in accordance with ASTM C39. A flexural strength test was conducted on a beam of 100mm x 100mm x 500mm, following the guidelines outlined in the ASTM C78 standards. A test was performed to measure the resistance of a concrete disc with a thickness of 50 mm and a diameter of 150 mm to impacts, following the guidelines set by the ACI 544.2R standard. Chloride penetration resistance testing was conducted on a cube that was 50 mm thick, 100 mm in diameter, and chopped 150 mm from its original size. The testing was done according to the ASTM C 1202 standard. A water absorption test was conducted on a 150 mm-sized cube in accordance with ASTM C 1585.

3 Results and Discussion

3.1 Compressive Strength

The Figure 3 illustrates the comparison of the compressive strength achieved after 28 days for three types of concrete: normal concrete and concrete combining both latex and sisal fibres. Other investigations have discovered that an increase in latex content leads to a reduction in compressive strength due to the air entrainment caused by rubber latex[(17)]. Subash et al.[(18)] Improved the compressive strength of concrete by admixing the NRL. Nevertheless, the current study does not show a significant impact of this phenomenon since defoamer is added to the latex, which hinders the coalescence of latex particles in a cementitious system[(11)]. Increasing the dosage of latex from 0.5 to 2% results in a decrease in compressive strength of normal concrete by 4.5% to 10.9%.

The compressive strength of sisal fibre-reinforced concrete (without latex, i.e., NRL-0%) is seen to be 19.6% higher, compared to conventional concrete. The inclusion of latex and fibres can greatly improve compressive strength. The introduction of latex has not had any impact on the compressive strength when using lesser dosages of NRL. However, a slight reduction in compressive strength is only noticed at higher levels of latex dose.

Figure 4 provides a vivid representation of the dispersion of latex particles inside the matrix, specifically with a 2% addition of NRL. The figure demonstrates the presence of a consistent network of latex films that coat the hydration products. This coating has the potential to slow down the hydration process. Furthermore, there is a retardation in the development of hydration products in concrete when styrene butadiene rubber latex is present. The decrease in compressive strength found at larger dosages of latex can be attributable to the aforementioned cause.

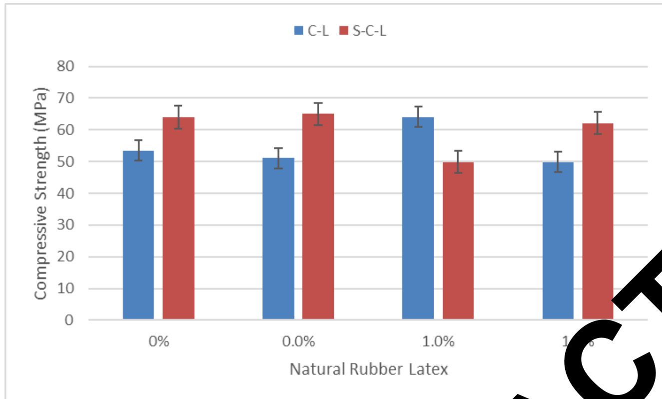

Fig 3. Compressive strength sisal fibre reinforced concrete with NRL

Fig 4. SEM image of Latex films which covers hydration products like a shield

Figure 5 illustrates a progressive decrease in bulk density as the latex content increases in both fibre-containing and fibre-free mixes. The addition of 2% latex to the concrete leads to a minimal reduction of 1.87% in bulk density, primarily caused by the presence of a defoamer. The little decrease in compressive strength can be attributable to the reduction in bulk density. By incorporating latex films into the matrix, small air pockets are formed, leading to a decrease in the total bulk density.

3.2 Flexural Strength

Thepruttana et al.[19] made an extensive study on the flexural characteristics of sisal fibre reinforced cement composites and found that the latex ad sisal fibre have improved the flexural characteristics. Figure 6 demonstrates the influence of latex content on the flexural strength of conventional concrete and concrete with sisal fibre. The results indicate that the flexural strength of standard concrete showed a significant increase of 27% and 35% when adding 1% and 1.5% latex, respectively. The enhancement can be ascribed to the existence of latex films in the altered concrete, which act as reinforcement amidst the hydrated cement paste, as depicted in Figure 7 on a microstructural scale. When external forces are exerted on latex modified concrete, the latex films first absorb the stresses. After the film ruptures, the stresses are transmitted to the moistened matrix[20]. Thus, the latex films function as a form of safeguard, by assimilating and dispersing tension. This enables the concrete to endure higher levels

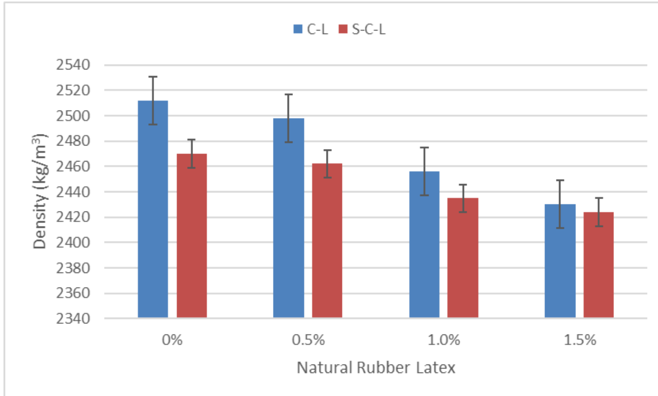

Fig 5. Bulk density of sisal fibre reinforced concrete with NRL

of bending tensile strains without fracturing, leading to a more significant enhancement in flexural strength.

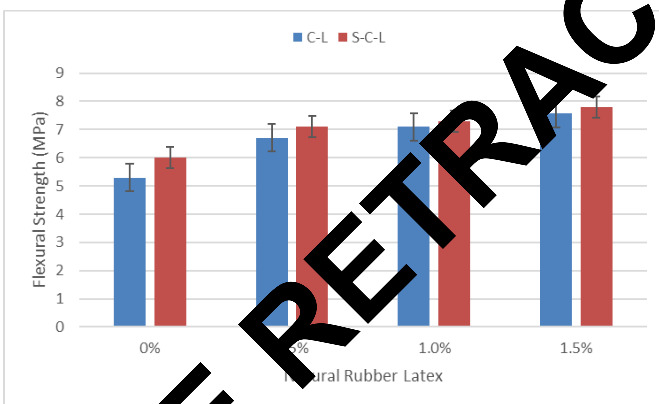

Fig 6. Flexural Strength of sisal fibre reinforced concrete with NRL

When 1.5% latex is added to sisal fibre reinforced concrete, the flexural strength increases by 39%. It is worth mentioning that adding 1.5% latex to conventional concrete can increase its flexural strength by 26% compared to concrete reinforced with sisal fibres.

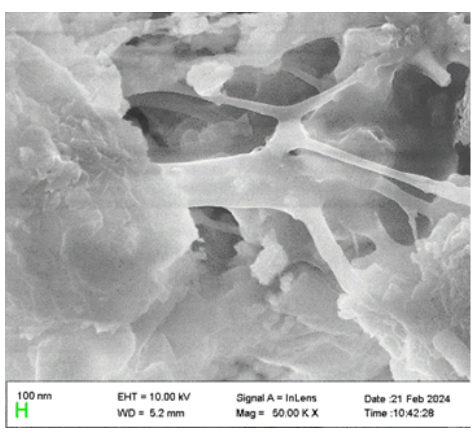

Fig 7. SEM image of Latex film which bridge hydration products

3.3 Water absorption

Figure 8 displays the water absorption of concrete that has been treated with latex, as well as concrete that contains both fibre and latex.

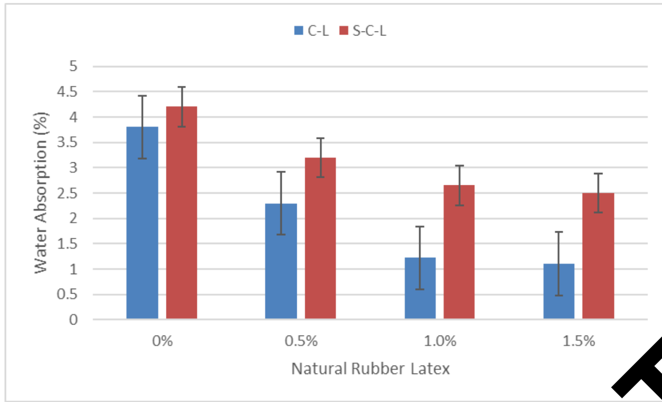

Fig 8. Water absorption of normal and fibre reinforced concrete with NRL

By incorporating latex into the standard concrete mixture, the water absorption rate decreases significantly from 3.8% to just 1.1% when using a 1.5% latex concentration. Prior studies have demonstrated that synthetic latexes exhibit resistance to water and capillary absorption, rendering them a highly promising option for concrete applications[21]. While the inclusion of fibres greatly improves the mechanical characteristics of concrete, the ability to resist water absorption is lower in both fibre-reinforced concrete with and without latex compared to concrete without fibres. The scanning electron microscope (SEM) image depicted in Figure 9 has yielded significant insights into the vulnerable interface between fibres and paste in concrete. It has revealed that concrete containing fibres allows for more water infiltration due to the presence of additional space. Indeed, the use of latex has effectively decreased the water absorption sisal fibre reinforced concrete, as depicted in Figure 8. This positive outcome has the potential to facilitate the creation of concrete structures that are more resilient and have a longer lifespan by using latex and fibres.

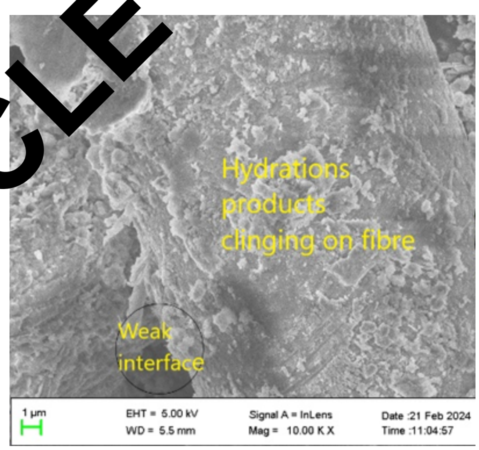

Fig 9. Fibre-hydrated cement paste interface

3.4 Resistance to penetration of chloride ions

The results of the chloride ion ingression test are presented in Figure 10. Decreased electric charge flowing through the sample signifies enhanced resistance to the infiltration of chloride ions, whereas a greater charge value suggests superior permeability. The electrical conductivity of concrete in the absence of latex indicates that it has low permeability to chloride ions, with a range of 1000 C to 2000 C as per ASTM C 1202. By including a mere 1% of latex, the chloride permeability is determined to be below 1000 C, signifying an exceptionally minimal permeability to chloride ions. The results indicate that an increased latex content in the mixture composition resulted in a more significant decrease in the penetration of chloride ions. This phenomenon may be attributed to the formation of latex films, which efficiently obstruct the transmission of chloride ions. This approach is particularly effective in extreme settings when the concrete is exposed to high levels of chloride ions, such as coastal areas or cold climates where de-icing chemicals are commonly used. The SEM images in Figures 7 and 9 shows evidence of the formation of these latex coatings, which subsequently lead to a reduction in permeability.

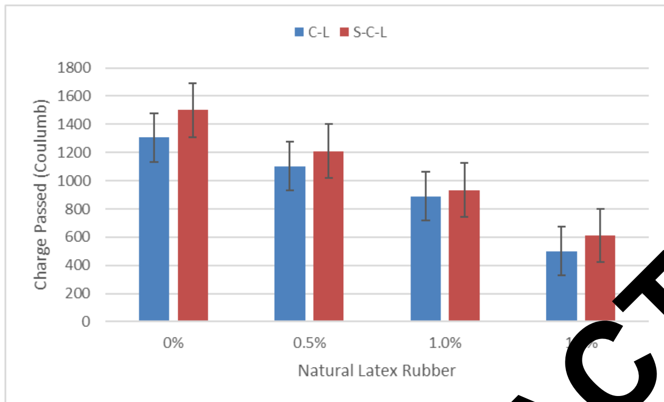

Fig 10. Chloride ion penetration of sisal fibre reinforced concrete with NRL

3.5 Resistance to impact force

Table 6 presents the results of the impact resistance test obtained for the normal concrete, fibre reinforced concrete and latex modified concrete mixtures. It is observed that the impact resistance of fibre reinforced concrete is increased as expected. It can be noticed that the number of blows to the first crack and final crack increases with an increase in latex dosage. Only a marginal increase in the number of blows is observed after the first crack until the ultimate failure. The failure pattern of the normal, latex modified, and fibre reinforced concrete specimens shown in Figure 11 indicates more indentation in fibre reinforced and latex modified concrete compared to normal concrete. Even though the fibre reinforced, and latex modified concrete specimens failed in a brittle manner under impact loading, the specimens were seen with an indentation before their failure. In Table 6, the results of the impact strength test for regular concrete can be seen, fibre-reinforced concrete, and latex-modified concrete. As expected, it has been seen that the impact strength of fibre-reinforced concrete has gone up. It can be seen that as the latex dose goes up, the number of hits to the first and last cracks goes up as well. There is just a slight increase in the number of blows seen following the initial crack to the point of complete failure. The failure pattern seen in Figure 11 demonstrates that the fibre reinforced, and latex modified concrete specimens exhibit more indentation compared to the conventional concrete specimens. Buritatum et al. [22] improved the fatigue Performance the pavement base by incorporating NRL Modified Cement stabilisation. Despite the fact that the fibre reinforced, and latex modified concrete specimens exhibited brittle failure under impact loading, they displayed an indentation prior to their ultimate failure.

Table 6. Test results of impact resistance study

Mixture ID	Mass of specimen (kg)	blows count (Initial crack)	blows count (Final crack)
C	3.19	151	152
C-L 0.5	3.09	189	196
C-L-1.0	3.014	279	288
C-L-1.5	3.011	399	412
S-C	3.209	459	469
S-C-L 0.5	3.19	474	481
S- C-L-1.0	3.16	491	495
S-C-L 1.5	3.132	501	505
S- C-L-2.0	3.105	510	513

The energy absorbed by the conventional and latex modified concrete is displayed in Figure 12. The energy absorbed by concrete is directly proportional to the latex content, regardless of whether it is standard concrete or fibre reinforced concrete. Incorporating a 1.5% natural rubber latex into conventional concrete leads to a significant 166% enhancement in energy absorption capacity prior to failure. The energy absorption and impact resistance of sisal fibre reinforced concrete and latex modified sisal fibre reinforced concrete are 203% and 231% higher, respectively, compared to conventional concrete.

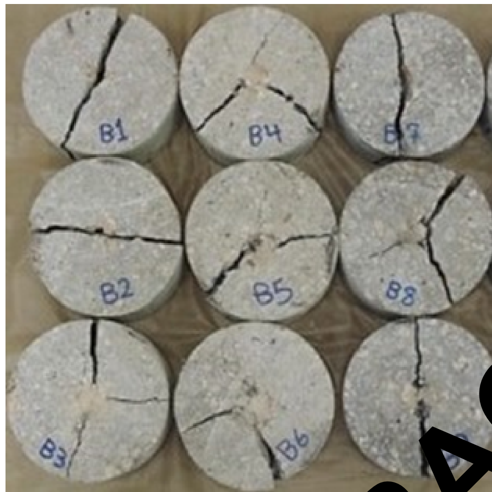

Fig 11. Failure pattern of sisal fibre reinforced concrete with and without latex

The combination of latex and fibres reduces stress concentration and prevents the formation of cracks when subjected to impact loading. The inclusion of latex film and fibres in the matrix impedes the propagation of micro cracks, therefore augmenting the toughness and ductility of the concrete.

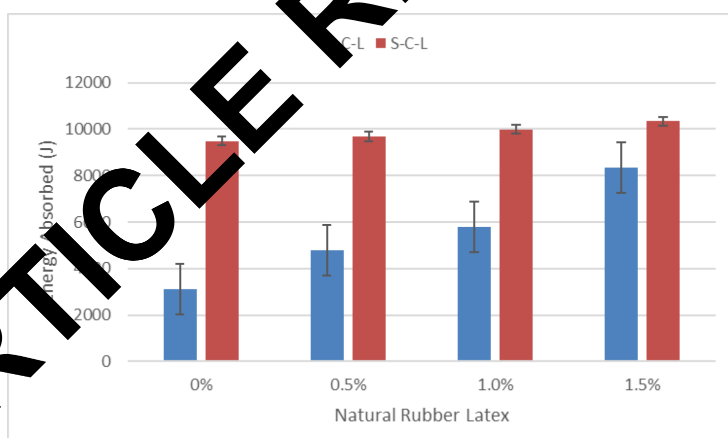

Fig 12. Impact energy absorbed sisal fibre reinforced concrete with NRL

The use of latex creates a unique bonding process at the interface, enhancing the toughness characteristics of both conventional and fibre-reinforced concrete. Therefore, the concrete possesses the capacity to withstand significant impact force while maintaining its structural integrity. The findings highlight the considerable potential of natural rubber latex concrete to greatly revolutionize various construction applications.

4 Conclusions

Utilisation of NRL and Sisal fibre is a relatively new technique in concrete technology. Hence, an experimental program was conducted to comprehend the uniqueness of utilizing natural rubber latex for modifying the characteristics of concrete. An extensive investigation was conducted on the impact of adding latex in combination with sisal fibres. The test results presented in this study offer useful insights on the efficacy of a sustainable polymer latex for various construction applications. Based on the materials and factors considered in the experimental inquiry, the following conclusions are derived:

1. Incorporating natural rubber latex into concrete, at a concentration of up to 1.5% by weight of cement, greatly enhances its flexural strength. The addition of 1.5% latex increases the flexural strength by up to 35%. A combination of 0.3% sisal fibre and 1.5% latex can result in a significant increase of up to 39% in flexural strength.
2. Increasing the amount of natural rubber latex in the concrete mixture from 0.5% to 1.5% causes a modest reduction in compressive strength and bulk density. This is because the latex introduces air into the mixture, which leads to the observed effects. However, it enhances the ratio between a material's bending strength and its compression strength.
3. Latex modified concrete surpasses regular concrete in terms of its ability to absorb energy during impact loads and its resistance to wear caused by abrasion. This makes it a highly efficient and sustainable choice for overlaying bridge decks, airport pavements, factory floors, and other similar applications. Concrete with a 1.5% latex modification shows a significant 166% increase in energy absorption. In the case of sisal fibre reinforced concrete with latex modification, the increase is even higher at 231%.
4. The addition of latex to ordinary concrete, which is classified as 'low' in terms of chloride permeability according to ASTM standards, has significantly reduced its permeability to a 'very low' level.

Based on the finding of this work, it is recommended that the incorporation of NRL and sisal fibre in concrete is another advancement in the field of concrete technology.

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