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MECHANICAL AND DURABILITY CHARACTERISTICS OF CONCRETE CONTAINING LOW-CONTENT NATURAL RUBBER LATEX

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Abstract

The most common weakness in concrete relates to its brittleness leading to sudden failure of structures. As latex polymer offers elastic characteristics to its composite, concrete is enhanced by adding natural rubber latex (NRL) to improve performance. Rubber latex-modified concrete compositions containing a lower percentage of rubber latex in the range of 0.5% to 3% by weight of cement presented as rubber to cement ratio was studied. This study evaluated the performance of NRL concrete in terms of workability, mechanical strengths, impact resistance, and durability characteristics. It was found that the NRL concrete produced a lower slump compared to the control specimen concrete. Compressive and flexural strength increases up to 22% and 26% respectively compared to the control specimen as the percentage of NRL increases to 1% and decreases as the percentage of latex increases thereafter. However, the water absorption and penetration results produced adverse effects with increasing NRL. Thus, according to the result of this study, the rubber cement ratio of 1% is the most suggested and optimal value to be utilized, where it produces a positive effect on various types of concrete tests. The study also showed that the results of impact resistance indicated that increasing NRL in the concrete mixture improves its resistance to impact load by 1.1 to 2.3 times compared to control specimens.

Keywords: Compressive strength, Durability, Impact resistance, Mechanical properties, Natural rubber latex concrete.

1. Introduction

Most construction in the world is dominated by concrete in terms of construction materials due to the affordability and accessibility of its constituents. Concrete is non-homogenous material produced by combining cement, aggregate, and sand in a mixture of water. In most cases, cement is utilized as a binder material, and sand is used as a filler material to fill the spaces between the aggregate. Aggregate is the most prevalent material in concrete, occupying more than 70-80 % of the total volume of concrete and providing strength. Cement is the most common binding material used in construction today. Its primary purpose is to build concretes with high mechanical strength.

The durability of concrete, on the other hand, is significantly influenced by the surrounding environment. In addition, cement manufacture is a process that places a significant burden on the environment and uses a considerable amount of energy [1]. According to Hazarika et al. [2] the production of cement contributes to 4% of the total world's carbon dioxide emission. Creating more sustainable materials and methods of producing concrete without compromising its qualities are vital to satisfy the demand for concrete manufacturing.

To achieve sustainability in concrete production, current processes can be improved, new concrete mixes can be developed, innovative product design may be implemented, and the functionality of concrete-based goods can be enhanced throughout their service life. According to Shanmugavel et al. [3] the internal structure of concrete needs to be strengthened to become resistant, and the durability of concrete structures will be increased [3].

Various studies have been reported in improving the properties of concrete through sustainable solutions such as the substitution of cement or aggregate with alternative materials and incorporation of admixture, as well as the addition of material known as additive. According to Bahranifard et al. [4] researchers are interested in determining whether the presence of admixtures affects the ability to get the correct quantities of components in concrete.

Because of this, the characteristics of concrete may be adjusted by adding natural elements sourced from renewable sources and readily available in the area. These additions result in improved strength and a longer lifespan for traditional concrete. Okba et al. [5] state that incorporating polymer additives into cement concrete results in modified cement concrete, which is superior to conventional concrete in terms of its ability to achieve the required outcomes. Concrete and mortar both benefit from the inclusion of the polymer since it improves the material's workability and tensile strength, bond strength, and impact resistance. The concrete becomes less permeable because the polymer forms a layer on the cement and aggregate, preventing moisture from penetrating the cement matrix. This, in turn, reduces the ability to retain moisture, corrosion, and environmental assaults on the concrete [6].

In most cases, additives are derived from synthetic polymers, which promote the emission of harmful substances into the environment [3]. In addition, the cost of such chemical compounds tends to be relatively high. In contrast to its synthetic polymer, natural rubber latex (NRL) originates from a renewable source and is considered a natural polymer; it is also more durable and has minimal health risks. Natural rubber latex is a product formed naturally from the "Hevea Brasiliense's tree," also known as the "Para rubber tree," primarily found in tropical countries such as Malaysia, Indonesia, Sri Lanka, India, and Brazil. Natural rubber latex is formed either due to the polymerization of isoprene (C_5H_8) or the light joining of the monomers of isoprene in the shape of a long-tangled chain.

The natural rubber latex produced is a colloidal dispersion of rubber particles that is water-based and safe for the environment. Southeast Asia is the most significant producer of natural rubber in the whole world. This region produces over 50 % of the world's rubber [7].

In general, concrete is fragile and has a low-stress resistance which motivated Nagaraj et al. [8] to incorporate polymeric substances to enhance the capacity of concrete by improving its ductile properties. Polymer latexes may impact conventional concrete's physical, mechanical, and long-term durability features. Nagaraj et al. and Subash et al. [8, 9] identified that the type of latex used, and the quantity of latex concentration present in the mixture are important parameters for the variations in the qualities of the concrete. Because of this, using natural rubber latex-modified concrete is of utmost importance since it can potentially improve conventional concrete's performance, resulting in a new mixture with increased advantages.

Polymers also create high adhesion between the particles in concrete, which helps enhance the resistance of concrete to abrasion, erosion, and impact. Muhammad and Ismail [10] found that experimental examinations on latex-modified concrete samples in hostile situations also demonstrated excellent outcomes in aggressive environments which were able to curb the attack from H_2SO_4 and Na_2SO_4.

The addition of rubber particles that are flexible and deformable might improve the characteristics of concrete by improving its brittleness and durability effect [11]. It is stated that polymers have long-chain structures, resulting in a developed network bonding structure. This improves the strength of natural rubber latex-modified concrete [9]. However, there are limited studies reported on the influence of natural rubber latex as admixture materials in concrete concerning their performances in workability, mechanical, and durability properties. Therefore, this investigation is carried out to study the effect of NRL addition on fresh and hardened concrete performances in terms of the workability, mechanical characteristics, and durability of concrete.

In this study, the supply of NRL is obtained from the Malaysian Rubber Board which is locally taken from rubber trees in Malaysia. This study aims to explore the viability of incorporating concentrated natural rubber latex into concrete as an admixture. The results of this study provide a scientific contribution on natural rubber latex polymeric materials to the engineering properties of concrete and may be utilized as a benchmark for future research.

2. Experimental Program

An experimental program was initiated to investigate the effect of NRL on the performance of concrete. The experimental work comprises raw materials preparation, design mix, specimen preparation and strength tests. The used natural rubber latex (NRL) was in the form of concentrated latex, comprised of 61% dry rubber concentration and non-rubber components such as water and protein. The amount of natural rubber latex (NRL) added to the concrete was measured based on the percentage of the total weight of cement represented by the rubber/cement (R/C) ratio. The amount of NRL used at varying rates of 0.5%, 1%, 1.5%, 2%, 2.5%, and 3% of the total weight of cement.

The target concrete strength of 30 MPa and the constant water-cement ratio of 0.47 were used as a basis in identifying the mix design. A total of 7 mixtures including the control mix were designed as shown in Table 1, which varies by NRL content. The experimental work comprises the fresh concrete test, mechanical properties test, and durability tests.

Table 1. Concrete mixture and constituent per 1m^3. Cement (471 kg), Fine aggregate (671 kg), and Coarse aggregate (992 kg).

Mix ID	R/C (%)
M0	0
M1	0.5
M2	1.0
M3	1.5
M4	2.0
M5	2.5
M6	3.0

2.1. Materials

The materials used in producing the NRL concrete were cement, coarse and fine aggregates, water, and concentrated natural rubber latex. Cement of ordinary Portland cement complying to MS EN 197-1: (2014) was utilised in this study. The cement with properties of a specific gravity of 3.15 kg/m^3, a specific surface area of 3150 cm^2/g, and a grey colour was incorporated.

The coarse aggregate used in this study is crushed natural stone with a maximum size of 20 mm and fine aggregate comprises particles with dimensions ranging from 4.75 to 0.125 mm. The fine aggregate used was sourced from river sand.

The addition of natural rubber latex (NRL) into concrete in this study functions as an admixture. The NRL in fresh state was supplied by the government-related agency in Malaysia named Malaysian Rubber Board (MRC) which was obtained from locally harvested rubber trees as shown in Fig. 1. The concentration of latex in NRL used in this study comprised 61% of dry rubber content. Table 2 shows the composition of natural rubber latex.

Table 2. Composition of natural rubber latex.

Components	Content (%)
Dry rubber	61.05
Total solid	59.87
Alkalinity (NH_3)	0.30

Fig. 1. Natural rubber latex (NRL) in the fresh state.

2.2. Mixing method and test

The method of mixing was carried out according to ACI recommendations. The components were loaded into a mixer. The mix was started with the combining of dry components such as coarse aggregates, fine aggregates and cement into the mixer and mixing well for 1 minute. After that 70% of the mixing water was gradually added, and the mixture was mixed for 1.5 minutes. The remaining water was then added to the required concentrated NRL and incorporated into the mixture. To prevent the fresh concrete from coagulating, it required five to seven minutes of mixing time to produce a homogenous blend, and the method adhered to the ACI standard.

A total of 154 specimens were prepared to be used in the mechanical and durability properties tests which consisted of cubes, prisms, and cylinders. The distribution of specimens according to the type of test and size of specimens is shown in Table 3.

In mechanical properties, there were four types of tests conducted identified as compressive, split tensile, flexural strengths and impact resistance test which were conducted at concrete age of 7 and 28 days after curing. Compressive, splitting tensile, and flexural tests were conducted according to BS EN 12390 standard. An average value from 3 specimens was taken as strength for each test.

Table 3. Specimens matrix with the type of test.

Mix ID	Mechanical Properties						Durability Properties	
	Compressiv estrength		**Splitting Tensile Strength**		**Flexural Strength**	**Impact resistance**	**Water Absorption**	**Water Penetration**
	Cube (100 × 100 × 100)		Cylinder 100 × 200		Prism (100 × ×100 × 500)	Cylinder 100 × 50	Cube (100 × 100 × 100)	Cube (150 × 150 × 150)
Age	7	28	7	28	28	28	3	3
M0	3	3	3	3	3	1	3	3
M1	3	3	3	3	3	1	3	3
M2	3	3	3	3	3	1	3	3
M3	3	3	3	3	3	1	3	3
M4	3	3	3	3	3	1	3	3
M5	3	3	3	3	3	1	3	3
M6	3	3	3	3	3	1	3	3
Total	**42**	**42**	**21**	**7**	**21**	**21**		

*All size in mm.

For impact resistance, a modified drop weight test followed ACI 544 was used to identify the energy absorption of NRL concrete. During this test, the cylindrical specimen of 100 mm diameter and 50 mm height, was subjected to a series of loadings from a raised position. The number of strikes, N needed to reach the required degree of distress, as measured by the appearance of both the first fracture and failure cracks. The mechanism consists of a hammered drop with a weight of 13 kilograms dropped from 390 mm height into the specimen.

The steel ball was positioned in the centre of the specimen, and then the sample itself was placed on the plate inside the base plate, as shown in Fig. 2. The hammer ball was dropped many times, and the number of blows (hit) necessary to produce the first visible fracture on the top was counted and recorded. In addition, the number of impacts (N) which represented by number of blows that resulted in cracks opening such that concrete fragments began contacting the side walls was recorded. The initial crack resistance factor was determined using the values of N_1, and the final crack resistance factor was determined using the values of N_2. The equations 1 and 2 determined the impact energy at the initial and final cracks, denoted by the symbols E_i and E_f, respectively.

$$E_i = N_1 mgh \left(\frac{Kg.m^2}{s^2}\right) or (Nm) \quad (1)$$

$$E_f = N_2 mgh \left(\frac{Kg.m^2}{s^2}\right) or (Nm) \quad (2)$$

where,

m = mass of the drop hammer (kg),

g = acceleration caused by gravity (taken as 9.81 m/s^2),

h = height at which the drop hammer is released (mm).

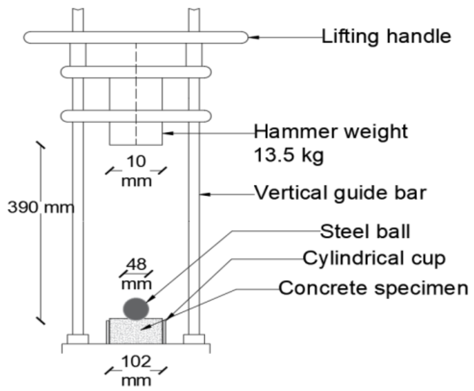


Fig. 2. Modified impact test equipment.

Apart from the listed tests, the workability of concrete was also measured to evaluate the fresh state and the workable level of the concrete through the slump test by complying with ASTM C143.

There were two tests conducted to measure the durability properties namely water absorption and water penetration. The water absorption test was performed using cube specimens under the standard test procedure specified in ASTM C 642-97. The concrete cube is placed in an oven to dry at 100 ℃ for a minimum period of 24 hours, then placed back into water for 2 days. The difference in concrete weight in these two conditions will be measured to represent water absorption in percentage.

The water penetration test was conducted based on the requirements of BS EN 12390-8:2000 specifications, using cube samples of 150 mm. The specimens were held at a water pressure of 500 kPa for three days in the apparatus. After that, the concrete cube is removed from the apparatus and cut into two halves, each subject to a different water pressure. On the specimen, the waterfront was identified as soon as the split face had dried to the extent when the water penetration front was evident after the split had previously obscured it and the highest depth of water penetration was measured.

3. Results and Discussion

This section is organized according to the fresh properties, mechanical properties and durability properties results of NRL concrete. The discussion presented the effect of NRL on concrete properties and the identification of the optimum content to be used in satisfying the fresh state and strength of working concrete.

3.1. Fresh properties

A slump test was utilized to evaluate the fresh properties of natural rubber latex concrete. By observation, the coagulation process of NRL produces a lump during mixing could affect the workability of concrete reflects the findings of this study which show a reduction trend in workability.

The result of the slump tests is shown in Fig. 3. Generally, the slump dropped with the increase of NRL content. The slump value for the control mixture M0 was 90, whereas the other slump values were 84 mm, 72 mm, 65 mm, 50 mm, 45 mm, and 38 mm for the mixes with NRL content of 0.5%, 1%, 1.5%, 2%, 2.5%, and 3%, respectively. Control mixture M0 and mixture containing NRL up to 1.5% represented by M1, M2 and M3 achieved the minimum slump limit for the designated mix. However, the other mixture did not achieve the minimum requirement slump limit.

Mixtures M1, M2, M3, M4, M5, and M6 had their workability decreased by NRL by 6.67%, 20%, 27.78%, 44.44%, 50%, and 57.78%, respectively, in comparison to the control mix, M0. The abrupt reduction in a slump can observed by M4 in comparison to its closer counterpart M3 with a reduction of 34.2%. This result is consistent with what was discovered by Plangoen [12]. This is because the NRL fills the pores and gaps in the concrete while still in its fresh state, transforming the concrete into a solid paste reducing its flow and becoming more viscous.

Nevertheless, a prior study found that the presence of an NRL particle in the concrete mix makes the mix less fluid which allows the dried NRL particles in the polymer to fill the pores in the mix and keep the concrete from drooping which reduces the mobility of mix by disabling the free dispersion of the fresh state concrete [9,13]. This is also influenced by the occurrence of rapid setting of latex rubber which formed as a white lump in the fresh mixes, and this creates weak chains that steadily gain enough strength preventing the mix from achieving the required homogeneity [14]. This appears to lower the amount of mixing water that is used by trapping part of it in its spongy interstices, and this prevents the mix from achieving the required homogeneity during mixing.

3.2. Mechanical properties

3.2.1. Compressive strength

Concrete cubes were produced and cured in water for specific testing ages according to BS EN 12390-3. Each mix has three replicate specimens, and the average value is taken to represent the compressive strength. The results of compression strength at 7 and 28 days are shown in Fig. 4.

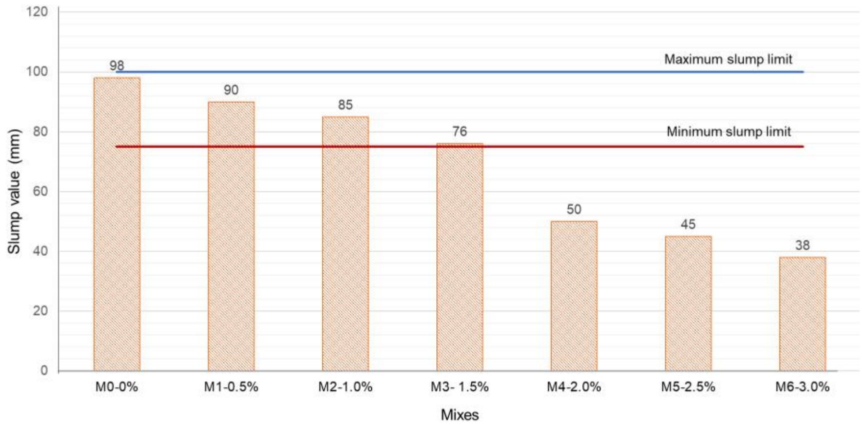


Fig. 3. Slump test results.

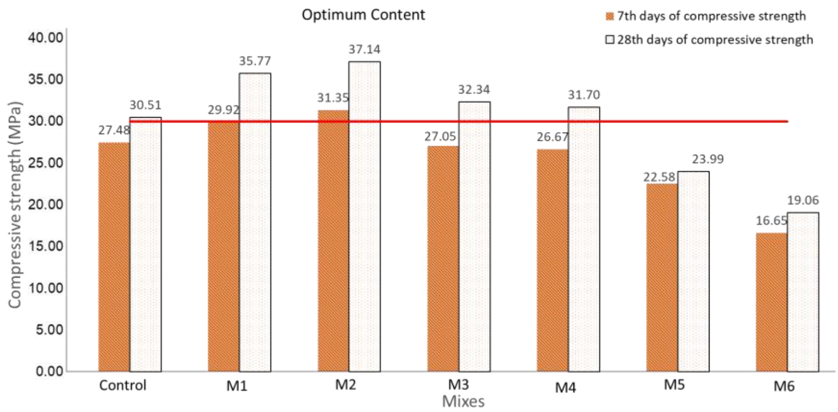


Fig. 4. Compressive strength results.

Overall, the strength of both ages 7 and 28 days show a similar trend beginning with an increment of strength before dropping thereafter depending on the amount of NRL addition. At seven days, the compressive strength of the control mix (M0) without NRL was 27.48 MPa. Adding 0.5% NRL represented by mix M1 increased the compressive strength to 29.92 MPa, while the compressive strength of M2 with 1% NRL was further improved to 31.35 MPa.

However, when the proportion of NRL increased to 1.5% (M3) and 2% (M4), the compressive strength decreased to 27.05 MPa and 26.67 MPa, respectively. Further increasing the NRL proportion to 2.5% (M5) and 3% (M6) resulted in a significant drop in compressive strength to 22.58 MPa and 16.65 MPa, respectively. Compared to the control mix M0, the strength of mixes M1 and M2 was enhanced by 8.89% and 14.08%, respectively, due to the low level of NRL added.

In contrast, the compressive strength of M3 was reduced by 5.59 %, M4 by 2.95 %, M5 by 17.84 %, and M6 by 39.40 % compared to M0 due to the increase in the addition level of NRL. These results were consistent with the previous research which demonstrated that increasing the quantity of natural rubber latex decreased concrete compressive strength [13].

For strength at 28 days, the control mix produced a compressive strength of 30.51 MPa. Adding 0.5% of NRL (M1) increased the compressive strength to 35.77 MPa, and further improvement was observed in M2 with compressive strengths of 37.14 MPa. However, the compressive strength of M3 and M4 decreased to 32.34 MPa and 31.70 MPa, respectively. Significant decreases were observed in M5 and M6 with compressive strengths of 23.99 MPa and 19.06 MPa, respectively. Using the control mix M0 as a benchmark in 28 days, the strength of the mixes M1, M2, M3, and M4 was increased by 17.23 %, 21.72 %, 6.00 %, and 3.90 %, respectively. While strengths for mixes M5 and M6 were lower than control.

Overall, the result of this research provides insightful information on the effect of natural rubber latex (NRL) on the compressive strength of concrete. According to the earlier findings, including a low percentage of NRL, such as 0.5% (M1), can significantly improve the compressive strength of the mix. This enhancement can be attributed to NRL's properties, including its elasticity, high elongation, and packing effect which are able to improve the bonding between cement particles and aggregate when added at a suitable amount. According to the findings of this research, an increase in compressive strength for a concrete mix containing up to 1% natural rubber latex (M2) is regarded as the optimum dosage range for NRL in concrete.

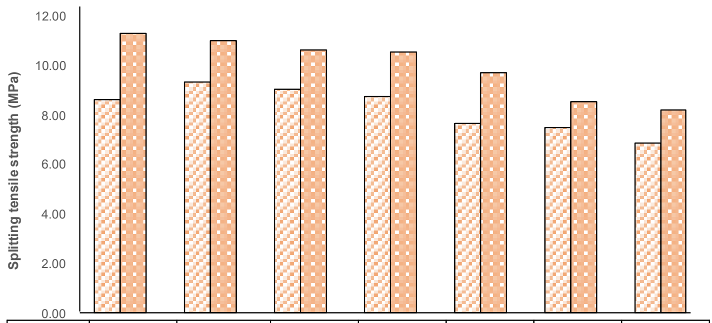
Any additional amount beyond this dose resulted in compressive strength beginning to decrease. This drop may result from an excessive quantity of natural rubber latex particles, which may impair the establishment of strong interparticle interactions and have a detrimental effect on the mortar's overall strength. A significant drop in compressive strength was detected in mixes with increasing proportions of NRL (M3 to M6), a clear indicator that an excessive amount of NRL adversely affects the strength development of the concrete. These findings are consistent with those found in other research, which revealed a decrease in strength alongside an increase in NRL content [13].

This is mainly due to the reduction of the hydration process of cement which is prevented by latex particles deposited on cement's particles resulting in a decrease in cement matrix strength and further reduced overall compressive strength [15]. It is essential to find an appropriate balance between the desirable features that NRL can provide without compromising the strength of concrete. The optimum content of NRL to produce acceptable compressive strength is shown by M2 with NRL of 1%.

3.2.2. Splitting tensile strength

A splitting tensile test is a method used to measure concrete's capacity to endure loads that are applied in tension. A tensile strength test was performed on concrete cylindrical samples at a loading rate of 1.57 kN/s at 7 and 28 days. Figure 5 shows the results of splitting tensile strength.

Generally, the tensile strength was dropped for both 7 and 28 days of age. The strength drop was started by M2 and M1 for 7 and 28 days. This reflects that at 28 days, the inclusion of NRL caused a negative effect immediately on tensile strength.



	M0	M1	M2	M3	M4	M5	M6
7 days	8.62	9.33	9.04	8.77	7.66	7.49	6.89
28 days	11.31	11.02	10.65	10.58	9.72	8.53	8.20

Fig. 5. Splitting tensile strength with different percentages of NRL.

After seven days, the tensile strengths of mixes M1, M2, M3, M4, M5, and M6 were 9.33, 9.04, 8.77, 7.66, 7.49, and 6.89 MPa, respectively. The strength produced by mixes M1, M2, and M3 were higher compared to control, M0 by 8.24%, 4.87%, and 1.74%, respectively. However, the other mixes M4, M5, and M6 showed strength reduction of 11.10%, 13.08%, and 20.04%, respectively. In addition, the values of tensile strength at 28 days for M1, M2, M3, M4, M5, and M6 were 11.02, 10.65, 10.58, 9.72, 8.53, and 8.20 MPa, respectively. In addition, as compared to the control mixture M0, the mixtures M1, M2, M3, M4, M5, and M6 exhibited declines of 2.51%, 5.85%, 6.46%, 14.06%, 24.56%, and 27.52%, respectively. The higher the content of NRL addition, the higher the strength reduction for 28 days.

The reduction in tensile strength can be explained by weaker bonds between the cement matrix in the presence of rubber latex due to the nature of the NRL, which agglomerates, weakening the bond between the aggregates. The higher content of NRL would reduce the bond between cement matric and aggregate which due to agglomerate formation in the mix thus increasing the brittleness and leading to the reduction in tensile strength.

The trend shown by the results suggests that adding NRL to the concrete mix results in the depreciation of the split tensile strength of the samples. However, a contrast finding was reported by Subash et al. [9] which shows that the tensile strength increased by the addition of NRL up to 6% showing brittleness compensated with ductility due to elasticity of latex concrete. This was caused by reduced brittleness due to the addition of polymer in the modified phase and as a result, the ductility of the specimen has improved.

3.2.3. Flexural strength

The prism specimens of concrete were tested after 28 days of age using four-point loading at a rate of 0.1 kN/s to measure its flexural strength. The ability of a concrete prism to withstand failure in bending is referred to as its flexural strength. Figure 6 shows the results of the flexural strength of all mixes tested. It was found that adding natural rubber latex to the concrete increased its flexural strength by 0.5 to 3 % compared to the control mix, depending on the natural rubber latex content.

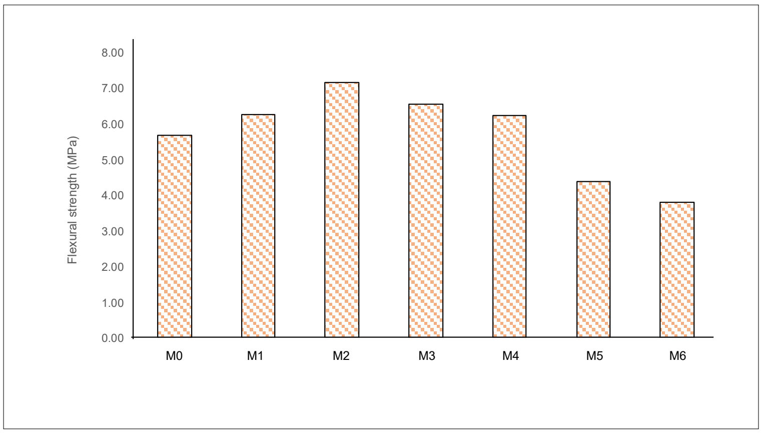


Fig. 6. Flexural strengths with different percentages of NRL.

The flexural strength of mixtures M0, M1, M2, M3, M4, M5, and M6 is 5.69 MPa, 6.26 MPa, 7.16 MPa, 6.56 MPa, 6.26 MPa, 4.39 MPa, and 3.81 MPa, respectively. At a low level of latex, an improvement of 10.14%, 26.00%, 15.36%, and 10.07% in flexural strength can be observed in M1, M2, M3 and M4 compared to the control mix, M0, respectively. This was because adding latex in the correct amount to the mix is advantageous as it provides flexibility capabilities [9].

Other than this, presumptions that the flexural strength of NRL-concrete has contributions from both cementation bonds and NRL films. For a particular w/c, the increase in latex increases the NRL films which reinforce the NRL-concrete matrixes and enhance the flexural strength of NRL-concrete; meanwhile, it reduces the cementation bonds [16]. The inclusion of latex beyond 2% resulted in lower strength values as observed in M5 and M6. An increasing level of NRL (2.5-3%) lowered the M5 and M6 mixes by 22.84% and 32.95% in comparison to the control M0.

A sudden drop in strength was observed by M5 in comparison to their immediate mix, M4. This may be due to the increasing amount of NRL exceeding the optimum level causing excess latex over the optimum quantity for maximum strength. Excess latex beyond that which is sufficient to occupy voids and microstructural cracks in the control mix might prevent the aggregate particles from being closely parked, thereby developing weak regions for undue cracks during the flexural test [17].

Therefore, concerning flexural strength development, the optimum level of latex to be incorporated into the concrete mix to produce the highest flexural strength is 1%.

3.2.4. Impact resistance

The impact drop weight test is commonly used to assess the resistance and toughness of concrete. The energy absorbed during impact represents the material's ability to withstand sudden loads or impact forces. The test was conducted in all batches. Table 4 shows the number of blows produced by each mix. The parameters that remain constant throughout the test are the weight of the hammer (13.5 kg), acceleration due to gravity (9.81 m/s^2), and the height of the drop hammer (0.39 m). The number of blows (N) indicates the number of repetitions performed for each mix until the crack formed on the surface of the concrete. Eq. (2) was used to calculate the energy absorbed.

Table 4. Impact drop weight test data.

Mix	Number of blows (N) Mean	Acceleration due to gravity (m/s^2)	Height of drop hammer (m)	Energy Absorbed (Nm)
M0	3	9.81	0.39	154.95
M1	3.33	9.81	0.39	171.99
M2	4	9.81	0.39	206.60
M3	4.67	9.81	0.39	241.20
M4	5	9.81	0.39	258.25
M5	6	9.81	0.39	309.90
M6	7	9.81	0.39	361.55

The impact resistance of rubber concrete was recorded in terms of the number of blows required for producing the first visible crack (N1) and ultimate failure (N2) of the specimen. Table 4 shows that the mean number of blows (N) required to cause the first crack and ultimate failure increases gradually with rubber content.

As can be seen in Fig. 7, the energy absorption for the control mixture M0 was 154.95 Nm, whereas the other energy absorption values were 171.99 Nm, 206.60 Nm, 241.20 Nm, 258.25 Nm, 309.90 Nm, and 361.55 Nm for the mixes of 0.5%, 1%, 1.5%, 2%, 2.5%, and 3%, respectively. There is a good relationship between the energy absorption and the amount of NRL with the fitting regression linear line presented by y = 33.831 x + 108.17 with an excellent R^2 of 0.9746.

As the NRL value increases, the energy absorption values increase. These observed that the energy absorption of concrete with NRL increases between 1.1 to 2.3 times compared to the control mix. Natural rubber latex has several inherent properties that can produce concrete with more impact resistance. Rubber particles can act as energy dissipaters and improve the toughness and ductility of the material. It may help absorb and distribute the impact forces, thereby increasing the energy absorption capacity of the concrete.

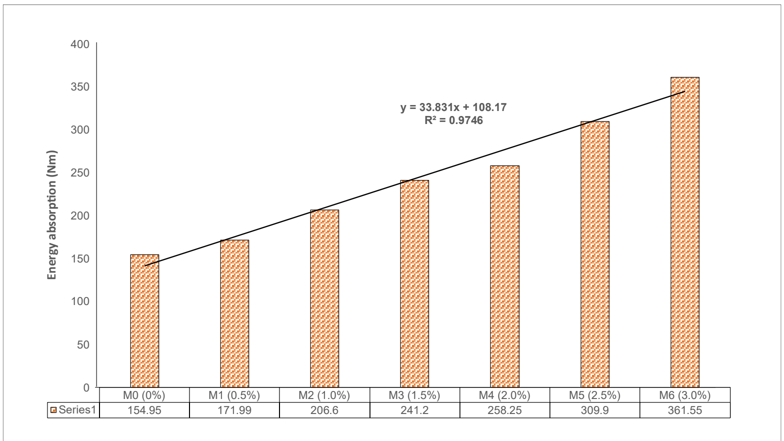


Fig. 7. Energy absorption for impact resistance of various mixes.

Hence, the results indicate that increasing the proportion of natural rubber latex in the concrete mixture improves its resistance to impact. The fact that the specimens can retain a steadily increasing amount of energy while being subjected to an increasing number of impacts indicates a positive effect on the concrete's durability and capacity to sustain impact load.

3.3. Durability properties

3.3.1. Water absorption

The test for water absorption is used to determine whether concrete can prevent water absorption. The water absorption of NRL concrete was evaluated using a weight change test at 28 days using dry and wet weights. The difference between the wet and dry weights in percentage was then calculated. The result of water absorption capacity with various mixes is shown in Fig. 8.

The figure demonstrates an abrupt increase of absorption value when 0.5% NRL, represented by M1, was added to the concrete compared to the control specimen. This, however, is not consistent with other mixes containing NRL where other shows a relatively lower amount of absorption. Higher water absorption presented by MI might be due to agglomeration of latex that occurred in this mix which produced greater size of pores causing higher capillary to the concrete.

However, increasing the NRL content of the concrete by more than 0.5% and up to 2% results in a decrease in water absorption. Incorporating 1% NRL into the concrete allowed optimal water absorption. According to the findings by Harahap, et al. [18], the presence of more than 1.0% NRL results in a decrease in the absorption rate as caused by the presence of sufficient coverage of thin matrix polymeric film which blocks the pores within the cement matrix and hydrophobic characteristics possessed by NRL. In addition, NRL can produce a thin matrix layer that surrounds and conceals the pores of the cement matrix. On the other hand, the value of the concrete's absorption capacity grows in tandem with the proportion of NRL greater than 2%.

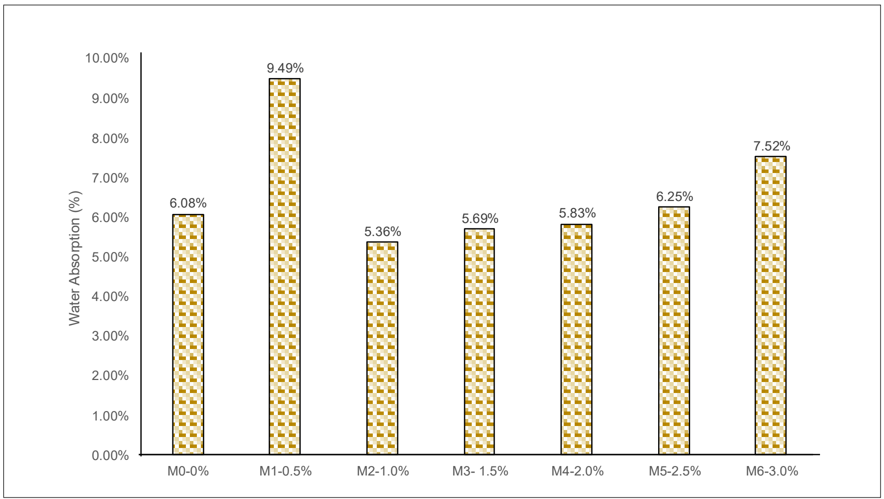


Fig. 8. Water absorption of NRL concrete.

The tendency of NRL to form agglomerates was the key factor that contributed to the rise in the water absorption coefficient. The NRL compound is difficult to distribute in the concrete, and it does not cover the voids as effectively as one would anticipate, allowing water to seep into the free voids [18]. The flow of the mixture requires a combination of surface water, which is the thin layer of water that develops on the surfaces of the concrete particles, and filled water, which is the water that fills the voids created between the mortar particles.

After NRL was introduced to the concrete mixture, there was a decrease in the flow of the concrete mixture and a thickening of the water on the top due to the polymeric effect. After NRL was added to the concrete, the water in the pores in the concrete matrix exhibited lower surface tension, and the pore fluid showed increased viscosity. In comparison, the latex-modified concrete with a percentage NRL of above 2.5% had higher water absorption ability in comparison to control except for M1. This likely resulted from an excessive amount of NRL rather than the optimal amount required for the best possible void filling.

Surplus NRL that is more than needed to fill the pore spaces may emerge at interface borders and prevent the aggregates from being compacted correctly. Therefore, the NRL will likely see an increase in voids because of the merging processes, which are often accompanied by a reduction in volume [13].

3.3.2. Water penetration

The water penetration test is an important indicator to evaluate the durability of concrete by measuring its ability to resist water penetration. This exhibits the water resistance of the concrete. At the age of 28 days, the water penetration of NRL concrete mixtures was examined by subjecting them to 500 kPa ± 50 kPa of water pressure for 72 ± 2 hours. M0 has a penetration depth of 15 mm in the control mix, which is the highest level of water resistance compared to the other mixes for 28 days of age. NRL content of 0.5 %, 1.0 %, 1.5 %, 2.0 %, 2.5 %, and 3 % of the cement to Mix M1, M2, M3, M4, M5, and M6, which resulted in a penetration depth of 25 mm, 36 mm, 45 mm, 54 mm, 65 mm, and 80 mm, respectively, after 28 days. This indicates that the permeability of concrete increased with increasing NRL content.

In addition, the amount of water that may penetrate concrete can also be utilized as a quality indication for the material. If the penetration depth is less than 50 mm, it is defined as "impermeable," if the depth is less than 30 mm, it is said to be "impermeable under aggressive conditions," as shown in Fig. 9.

The depth of water penetration produced by mixture M1 was 25 mm, which suggests that this mix is impermeable under aggressive conditions. In contrast, the depths of water penetration produced by mixtures M2 and M3 were greater than 30 mm but less than 50 mm, which indicates that these mixtures are impermeable [19]. However other mixtures M4, M5 and M6 are considered permeable concrete. This indicates that the presence of NRL increases the permeability of concrete. This trend may be interpreted by voids in concrete matrix which are not filled by the particle of NRL This also may be due to the formation of NRL agglomeration and their distribution within the mix and size spectrum and seems to produce higher capillary voids.

However, this needs to be confirmed by SEM analysis of the microstructure of concrete which can be considered in the scope of future study. Therefore, the suggested NRL content to be used is 1.5% to avoid any tendency for permeable concrete.

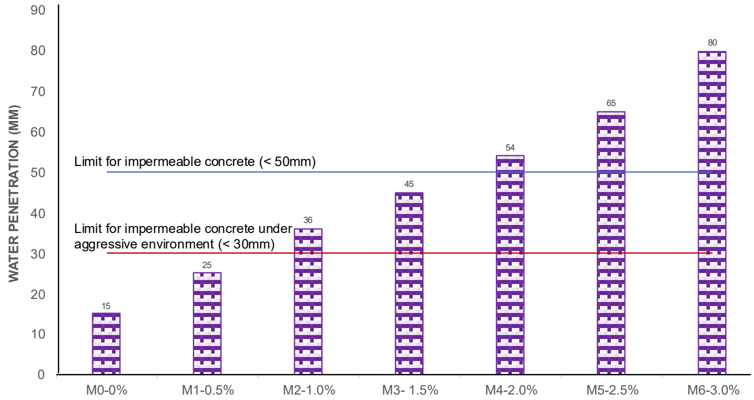


Fig. 9. Water penetration results.

4. Conclusions

This study investigates the performances of concrete containing a low content of NRL in terms of workability, mechanical, and durability properties through experimental testing. The slump test was used to evaluate the fresh characteristics of the concrete, while the compression, splitting tensile, flexural strength, and impact resistance under drop weight tests were used to assess the mechanical properties. Water absorption and penetration tests were carried out to determine the durability properties of concrete.

According to the investigation findings, incorporating NRL into the concrete composition, a marginal effect was observed in its properties and can be concluded as follows:

- The fresh properties of NRL concrete through the workability of slump test were obtained and identified that the reduction in workability was produced as the proportion of NRL increased. The minimum slump is achieved by mixes with NRL content of up to 1.5%. In physical observation made during the mixing, the white lump of latex forms due to the agglomeration process causing the reduction in the workability. Less workability also contributed by NRL occupying spaces and voids in the concrete, increasing its viscosity, and decreasing flow.
- The addition of NRL for up to 1% improved the 28 days compressive strength by 22%. But after this point, the compression strength started to drop. For splitting tensile strength, at 7 days shows a slight improvement between 1.7% to 8.2% produced by mixes with 0.5-1.5% NRL as compared to control. However, the strength at 28 days produced a negative effect by continuously decreasing in strength with increasing content of NRL.
- The flexural strength of the concrete exhibited variable findings, with some mixes demonstrating a gain in strength while others demonstrated a drop in strength which shows the highest strength produced by M2 with 1% NRL.

Impact resistance under the drop weight test indicates an increase as NRL increases.

- The durability properties of the water absorption and penetration tests address the fact that the addition of NRL had little effect on the water absorption characteristics of the concrete. However, a higher percentage of NRL particles in the mixture has the potential to weaken the bond between the cement and aggregate, thereby influencing long-term durability.
- Compressive, tensile, and flexural strength increase as the percentage of natural rubber latex increases up to the optimum content of 1% and decreases as the percentage of latex increases thereafter. However, the water absorption and penetration results produced adverse effects with increasing of latex content. Thus, according to the result of this study, the rubber to cement ratio (R/C) of 1% by weight is the most suggested and optimal value to be utilized where produces a positive effect on various kinds of concrete tests.

Overall, incorporating natural rubber latex (NRL) into concrete results in changes to the concrete's properties, both positive and negative. Although having a low NRL percentage might reduce the workability of concrete and improve certain hardened properties, such as compressive strength, flexural, impact resistance, and splitting tensile strength, having an excessive NRL percentage can lead to decreased strength and durability in concrete which mainly due to quick agglomeration rubber particle in mixing process. Therefore, carefully considering and optimizing the NRL content is required to improve and maintain concrete performances.

Nomenclatures

g	Acceleration of gravity (m/s^2)
h	Height of the drop hammer is released (mm)
m	Mass of hammer (kg)

Abbreviations

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
MRC	Malaysia Rubber Board
MS EN197	Malaysia Standard – Cement Part 1

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