International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(Research Article)

Assessment of the mechanical attributes via mathematical simulations for distinct sizes of morsel rubber

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International Journal of Science and Research Archive, 2025, 15(03), 1090-1099

Publication history: Received on 31 January 2025; revised on 07 March 2025; accepted on 10 March 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.15.3.0610

Abstract

Rubber waste is a significant environmental and health problem worldwide, resulting from the non-biodegradability of rubber products and increasing rubber production. The primary sources of rubber waste include discarded tires and waste generated during the production of rubber products. Environmental pollution and health risks result from the improper disposal of rubber waste, which includes burning and dumping in landfills. Rubber waste as a replacement for sand in concrete has gained attention in recent years due to the growing problem of rubber waste and the environmental benefits of reducing sand consumption. This research aims to see the variation in concrete properties by using distinct particle sizes of rubber waste as a partial replacement for sand in concrete. An experimental result has been produced by substituting morsel rubber waste particles for fine aggregates in concrete in amounts ranging from 0% to 10% while adding 2.5% to the standard concrete's strength benchmarks. The concrete with and without Bakelite plastic waste as aggregates was observed in the compressive, abrasion, impact energy, water absorption, water permeability, and microstructural properties tests, displaying good strengths. After strength parameters were examined, the most robust concrete was produced using fly ash-based concrete with a 7.5% BPW content. The addition of rubber waste can improve the properties of concrete, such as reducing its weight and increasing its energy absorption capacity. However, using rubber waste in concrete has some limitations, such as lowering compressive strength.

Keywords: Rubber Waste; Bakelite; Compressive; Mathematical models

1. Introduction

One of the many issues humans worldwide face is the increased utilization of natural assets. The building of reinforced concrete structures, which consume enormous amounts of concrete, is required to meet the ever-increasing demand for infrastructure improvement. Sand, one of the components of concrete, is occasionally in short supply, forcing the researchers to investigate the probability of using other materials that can partially substitute sand while making concrete. On the other hand, rubber waste is a growing environmental problem due to its widespread use in various products and the increasing volume of waste generated by a growing population. Rubber waste has several harmful environmental effects, including land, water, air, resource depletion, and climate change. To minimize these impacts, recycling and disposing of rubber products properly and using sustainable materials whenever possible is essential. By reducing the volume of rubber waste generated and improving its management, we can help to protect the environment and ensure a sustainable future. Burning waste tires is typically the quickest way to decompose them, but it produces many harmful gases that cause air contamination. Another option is storing them on undeveloped land, but this comes with issues, such as the risk of fire outbreaks or insects. Even though rubberized concrete is very lightweight, it is beneficial, and it has a severe strength issue. According to various findings, adding more rubber causes a substantial drop in rubberized concrete's elastic modulus and compressive and tensile strengths. Rubberized concrete is typically not advised for structures that must withstand heavy loads. It can be used in road construction, wall panels, insulated panels, etc. Ground rubber can be produced in various sizes, including fine, medium, and coarse. The addition of rubber

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waste to concrete has the potential to improve its properties, such as reducing its weight and enhancing its insulation, while also addressing the issue of rubber waste disposal. The addition of fine rubber particles to concrete has shown some improvements in its compressive strength and workability, but it can also lead to a decrease in the density of the concrete. Fine rubber particles have a larger surface area than larger particles, allowing for better bonding with cement, resulting in increased strength. However, the high surface area can also reduce the workability of the concrete, which can cause problems during placement and finishing.

Medium-sized rubber particles have been found to improve the workability and durability of concrete. They help to fill in the gaps between larger aggregates, resulting in more compact concrete with a reduced porosity. This leads to improved mechanical properties, such as increased strength and durability. However, the use of medium-sized rubber particles may lead to a reduction in the compressive strength of concrete.

Coarse rubber particles have been shown to have the most significant impact on reducing the weight of concrete. They provide good thermal and acoustic insulation, which can benefit specific construction applications. However, the addition of coarse rubber particles may harm the compressive strength and workability of the concrete, which may require a higher proportion of cement to be used to compensate.

In conclusion, the size of rubber waste used as a replacement for sand in concrete significantly affects its properties. Fine, medium, and coarse rubber particles have advantages and disadvantages, and a balance must be achieved between the desired properties and the potential drawbacks. Using different sizes of rubber waste in concrete can lead to a sustainable solution to the rubber waste problem while also improving the environmental performance of the construction industry.

2. Methodology

2.1. Material

The current study uses Pozzolana Portland cement according to IS 1489(2015), which has a specific gravity and consistency of 3.11 and 36%, respectively. The compressive strength of the cement after 28 days of curing is about 42.9 MPa, and it has 128- and 292-minute initial and final setting times, respectively. It uses fine aggregates with a specific gravity of 2.67, conforming to zone II according to IS: 383-1970. The present study employed coarse aggregate sizes of 20 mm and 10 mm with a specific gravity of 2.64 and 2.63, respectively. In this study, morsel rubber with three different size ranges is taken. Specific gravity for MRd1, MRd2, and MRd3 are 0.96, 1.09, and 1.14, respectively. Fine aggregate, coarse aggregate, and morsel rubber properties are depicted in Table 1. Fig. 1 shows the gradation curve for fine aggregate, coarse aggregate (10 and 20mm), and morsel rubber (MRd1, MRd2, and MRd3). Morsel rubber was used as the substitute for fine aggregate in the concrete.

Table 1 Properties of aggregate and morsel rubber

Properties	**Fine aggregate**	**Coarse aggregate**		**Morsel rubber**		
		10 mm	**20mm**	**MRd1**	**MRd2**	**MRd3**
Water absorption (%)	0.95	0.5	0.5	0.4	0.3	0.25
Fineness modulus	2.67	5.80	7.14	0.736	1.99	2.98

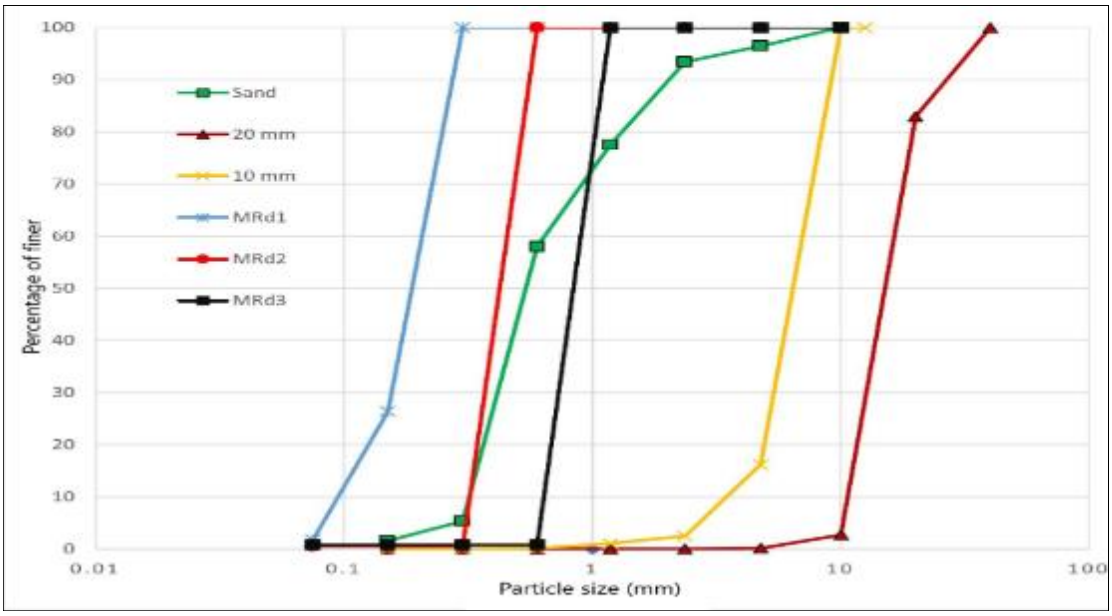

Figure 1 Gradation curve for aggregate (fine and coarse) and morsel rubber (MRd1, MRd2, and MRd3)

2.2. Mix proportions

In the present study, thirteen different types of concrete mix have been prepared using three different sizes of morsel rubber (MRd1, MRd2, and MRd3) and different percentages of morsel rubber (MR0.0, MR2.5, MR5.0, MR7.5, and MR10). Mix IDs of all the concrete mixes are listed in Table 2. MR0.0 is the control mix with 0% of morsel rubber. Other than the control mix, twelve types of concrete mix are there in which fine aggregate is substituted by morsel rubber at various percentages from 2.5 to 10% at the increment of 2.5%. Table 2 shows the weight of different materials used to prepare the concrete. A constant water-to-cement ratio (0.40) is used to prepare the concrete. Fine aggregates were replaced by morsel rubber based on their weight. A superplasticizer ranges from 0.8 to 1.9% in different concrete mixes to attain the constant compaction factor (0.9). Ingredients were combined, cast, and cured under the necessary guidelines of IS: 10262-2019.

Table 2 Concrete mix

Mix ID	Weight per cubic meter (kg/m^3)								
	Water	Cement	Coarse aggregate		Fine aggregate	Morsel rubber			Admixture
			10mm	20mm		MRd1	MRd2	MRd3	
MR0.0	157.6	394	420	631	842.00	0.0	0.0	0.0	3.15
MRd1MR2.5	157.6	394	420	631	820.95	2.5	0.0	0.0	5.52
MRd1MR5.0	157.6	394	420	631	799.90	5.0	0.0	0.0	5.91
MRd1MR7.5	157.6	394	420	631	778.85	7.5	0.0	0.0	6.70
MRd1MR10	157.6	394	420	631	757.80	10	0.0	0.0	7.50
MRd2MR2.5	157.6	394	420	631	820.95	0.0	2.5	0.0	4.00
MRd2MR5.0	157.6	394	420	631	799.90	0.0	5.0	0.0	4.73
MRd2MR7.5	157.6	394	420	631	778.85	0.0	7.5	0.0	5.52
MRd2MR10	157.6	394	420	631	757.80	0.0	10	0.0	6.30
MRd3MR2.5	157.6	394	420	631	820.95	0.0	0.0	2.5	3.55
MRd3MR5.0	157.6	394	420	631	799.90	0.0	0.0	5.0	4.33

MRd3MR7.5	157.6	394	420	631	778.85	0.0	0.0	7.5	5.12
MRd3MR10	157.6	394	420	631	757.80	0.0	0.0	10	5.52

3. Results and Discussion

3.1. Admixture requirement

The workability of several concrete mixtures with and without morsel rubber was tested, and the findings were evaluated. Workability reduces as the rubber content increases, while the conventional mixture holds a compaction factor value 0.90. Each time the morsel rubber was increased, the compaction factor of the concrete decreased. The continuous addition of morsel rubber particles creates a hurdle that obstructs suitable mixing. A similar pattern of results can be seen in Bisht and Ramana et al., adeboje et al. Bomp and Elghazouli et al., Jokar et al., and Alwesabi et al. In the present research, a suitable superplasticizer was added to various mixes with varying percentages of morsel rubber to achieve a compaction factor of 0.90.

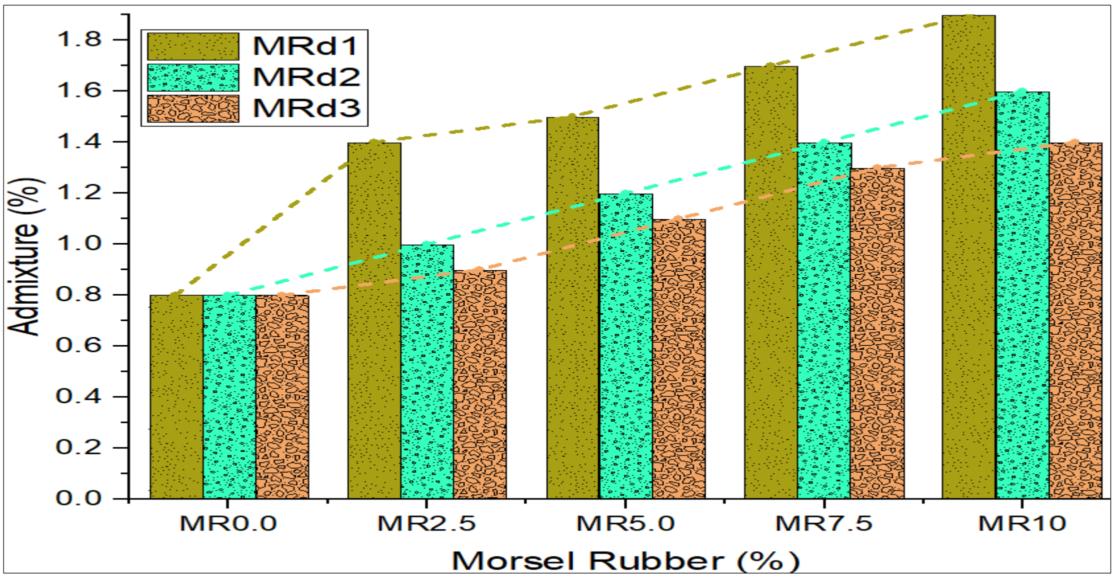

Figure 2 illustrates how the admixture content rises as the morsel rubber content rises in the concrete

When the size of the morsel rubber increases, MRd1 to MRd3, the requirement for the admixture in the concrete decreases, a decrease in the admixture requirement might be because when the particle size of the morsel rubber increases, the surface area decreases, leading to a decrement in the demand for admixture in the concrete.

3.2. Compressive strength

The compressive strength of the control mix (MR0.0) was obtained as 32.91 MPa after 28 days of curing. Figure 1 demonstrates the control mix's compressive strength and the concrete's varying percentage substitution of morsel rubber. Figure 3 also indicates that as the proportion of morsel rubber increases, the compressive strength of concrete decreases. The compressive strength of concrete was diminished by 5.70, 5.01, and 1.34% for MRd1, MRd2, and MRd3, respectively, compared to the control mix when the morsel rubber percentage increased from 0.0 to 2.5%. When the substitution level of morsel rubber increased up to 5.0%, the strength decreased by 11.5, 9.00, and 5.34 % for MRd1, MRd2, and MRd3, respectively, compared to the control mix. A maximum drop in the compressive strength was seen when the substitution level of morsel rubber increased to 10% compared to the control mix. The decrease in compressive strength was around 30.76, 26.01, and 22.65 % for MRd1, MRd2, and MRd3, respectively. The lack of grip between the smooth morsel rubber particles and cement paste usually causes compressive strength reduction. Another reason for the loss in compressive strength might be that when rubberized concrete is loaded, cracks will rapidly form around the morsel rubber particles as rubber particles are softer than the fine aggregates, causing quick rupture of the concrete. Morsel rubber particles are finer

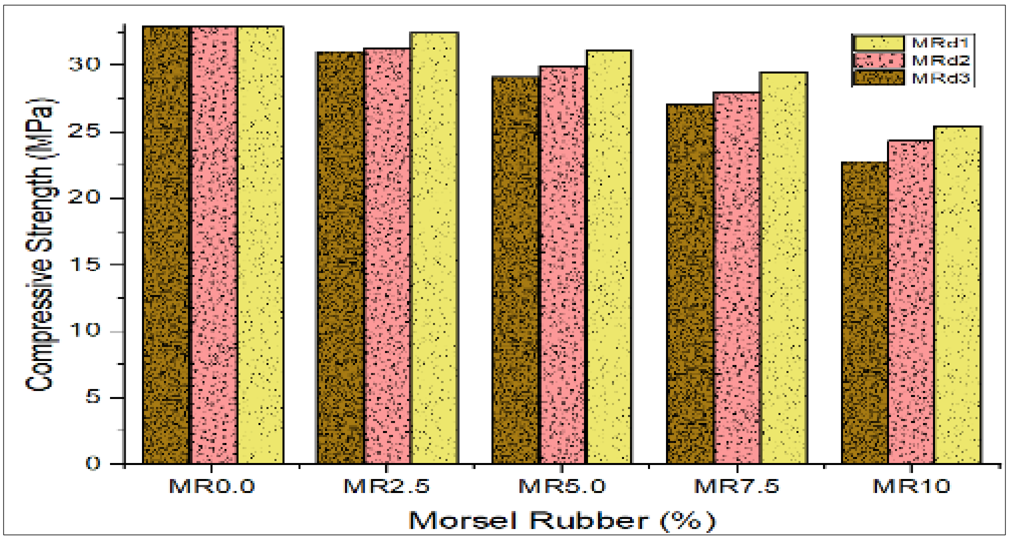

Figure 3 Experimental data for compressive strength for different sizes and content of morsel rubber

than fine aggregates, which generate more voids. This may also contribute to the reduction in compressive strength. Kunal and Ramana, Mousavimehr and nematzadeh (2019), yang (2019), chai (2019), adeboji (2020), alwesabi (2020) Rajaei. Guru prasad, adbulameer kadhim, and mohammed kadhim (2021) also noticed that compressive strength decreases with the increase in the morsel rubber content in the concrete. There is another trend that one can see from Fig.3, which is somewhat similar to that discussed above, that the size of the morsel rubber particle has a minor impact on the compressive strength of the rubberized concrete. From Fig., one can see that out of the three sizes used in the study, MRd1, MRd2, and MRd3, MRd3 appeared to have higher compressive strength than the other two sizes. Reduction in the compressive strength when MRd3 size morsel rubber particles were used in the concrete is 1.32 and 5.34 % at 2.5 and 5.0% replacement levels, respectively, compared to the control mix. The finer particle significantly reduces the compressive strength for a given amount of the morsel rubber. The concrete mixture with MRd3 size particles is incorporated into the concrete with a 2.5% replacement level, giving the maximum strength, 32.47 MPa, after 28 days of curing. The results of earlier studies also showed that the size, proportions, and surface textures of rubber particles significantly influence the compressive strength of rubberized concrete. also reported findings that finer particles significantly reduce the compressive strength of a given amount of morsel rubber compared to coarse particles.

3.3. Flexural strength

The flexural strength of the control mix (MR0.0) was obtained as 3.72 MPa after 28 days of curing. Figure 2 demonstrates the flexural strength of the control mix and the concrete's varying percentage substitution of morsel rubber. Figure 2 also indicates that as the proportion of morsel rubber increases, the flexural strength of concrete decreases for MRd1 and MRd2, but the flexural strength of the rubberized concrete having MRd3 particles increases at 2.5% of morsel rubber replacement. The flexural strength of concrete was diminished by 3.20 and 2.00% for MRd1 and MRd2, respectively, but for MRd3 particles, flexural strength was increased by 2.1% as compared to the control mix when the morsel rubber percentage increased from 0.0 to 2.5%. When the substitution level of morsel rubber increased up to 5.0%, the flexural strength decreased by 4.57, 3.44, and 1.12 % for MRd1, MRd2, and MRd3, respectively, compared to the control mix. A maximum drop in the flexural strength was seen when the substitution level of morsel rubber was increased up to 10% compared to the control mix. The decrease in flexural strength was around 18.87, 15.05, and 9.37 % for MRd1, MRd2, and MRd3, respectively. The specimens with MRd3 sizes morsel rubber replacement displayed higher flexural strength values than the control mix, most likely because of the influence of the rubber fibers. Compared to the control mix, the mixture with an MRd3 size particle with 2.5% content of morsel rubber exhibits a maximum flexural strength of 4.75 MPa at 28 days of curing. The advantage is that morsel rubberized concrete does not crack suddenly under bending like regular concrete does.

The lack of grip between the smooth morsel rubber particles and cement paste usually causes compressive strength reduction. Another reason for the loss in compressive strength might be that when rubberized concrete is loaded, cracks will rapidly form around the morsel rubber particles as rubber particles are softer than the fine aggregates, causing quick rupture of the concrete. Morsel rubber particles are finer than fine aggregates, which generates more voids, which may also contribute to the reduction in compressive strength. Kunal and Ramana, Mousavimehr and nematzadeh (2019), yang (2019), chai (2019), adeboji (2020), alwesabi (2020) Rajaei. Guru prasad, adbulameer kadhim, and mohammed kadhim (2021) also noticed that compressive strength decreases with the increase in the morsel rubber content in the concrete. There is another trend that one can see from Fig, which is somewhat similar to that discussed above, that the size of the morsel rubber particle has a minor impact on the compressive strength of the rubberized concrete. From Fig. 2. one can see that out of the three sizes used in the study, MRd1, MRd2, and MRd3, MRd3 appeared to have higher compressive strength than the other two sizes. Reduction in the compressive strength when MRd3 size morsel rubber particles were used in the concrete is 1.32 and 5.34 % at 2.5 and 5.0% replacement levels, respectively, compared to the control mix. The finer particle significantly reduces the compressive strength for a given amount of the morsel rubber. The concrete mixture with MRd3 size particles is incorporated into the concrete with a 2.5% replacement level, giving the maximum strength, 32.47 MPa, after 28 days of curing. The results of earlier studies also showed that the size, proportions, and surface textures of rubber particles significantly influence the compressive strength of rubberized concrete.

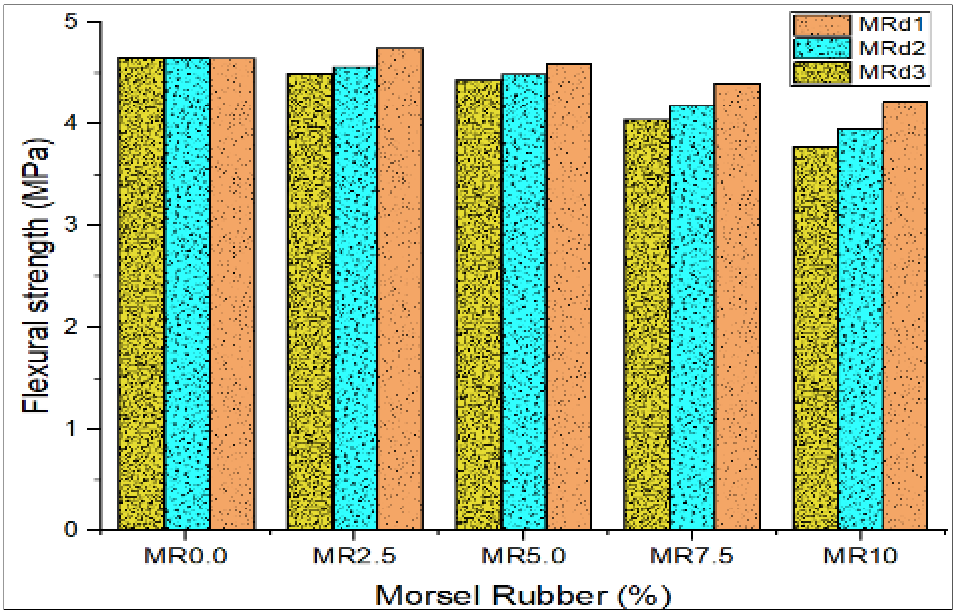

Figure 4 Experimental data for flexural strength for different sizes and content of morsel rubber

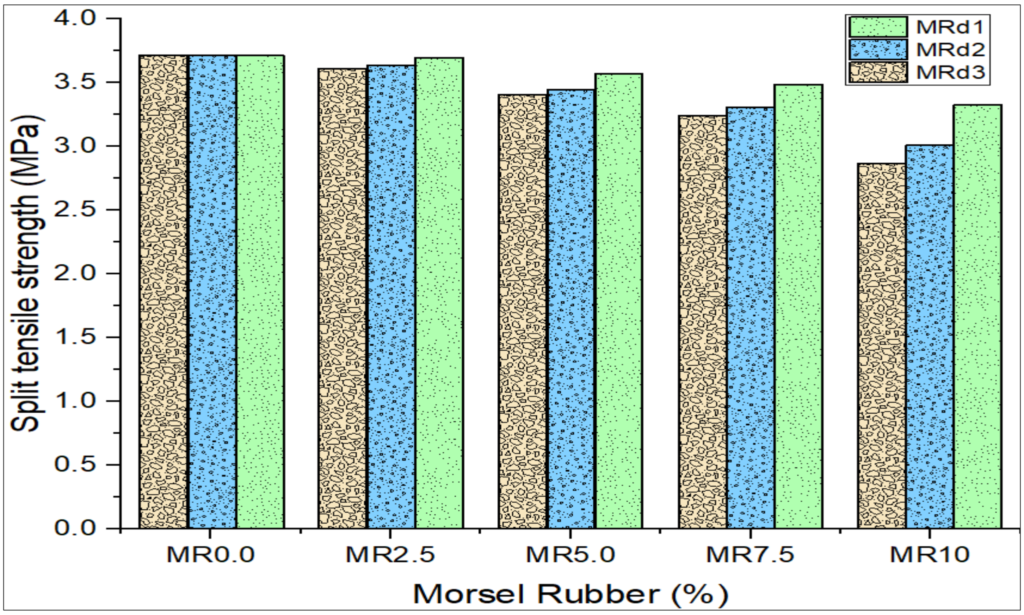

Figure 5 Experimental data for split tensile strength for different sizes and content of morsel rubber

$$a \times \left(\frac{MR(\%)}{10}\right)^2 + b \times \left(\frac{MR(\%)}{10}\right)^1 + c \times \sqrt{\left(\frac{MR(\%)}{10}\right)} + d$$

0 – 300 µ

Compressive strength

$$-0.349 \times \left(\frac{MR(\%)}{10}\right)^2 + 0.245 \times \left(\frac{MR(\%)}{10}\right)^1 - 0.199 \times \sqrt{\left(\frac{MR(\%)}{10}\right)} + 1.000$$

Flexural strength

$$- 0.168 \times \left(\frac{MR(\%)}{10}\right)^2 + 0.010 \times \left(\frac{MR(\%)}{10}\right)^1 - 0.035 \times \sqrt{\left(\frac{MR(\%)}{10}\right)} + 0.999$$

Split tensile strength

$$- 0.204 \times \left(\frac{MR(\%)}{10}\right)^2 + 0.032 \times \left(\frac{MR(\%)}{10}\right)^1 - 0.052 \times \sqrt{\left(\frac{MR(\%)}{10}\right)} + 1.000$$

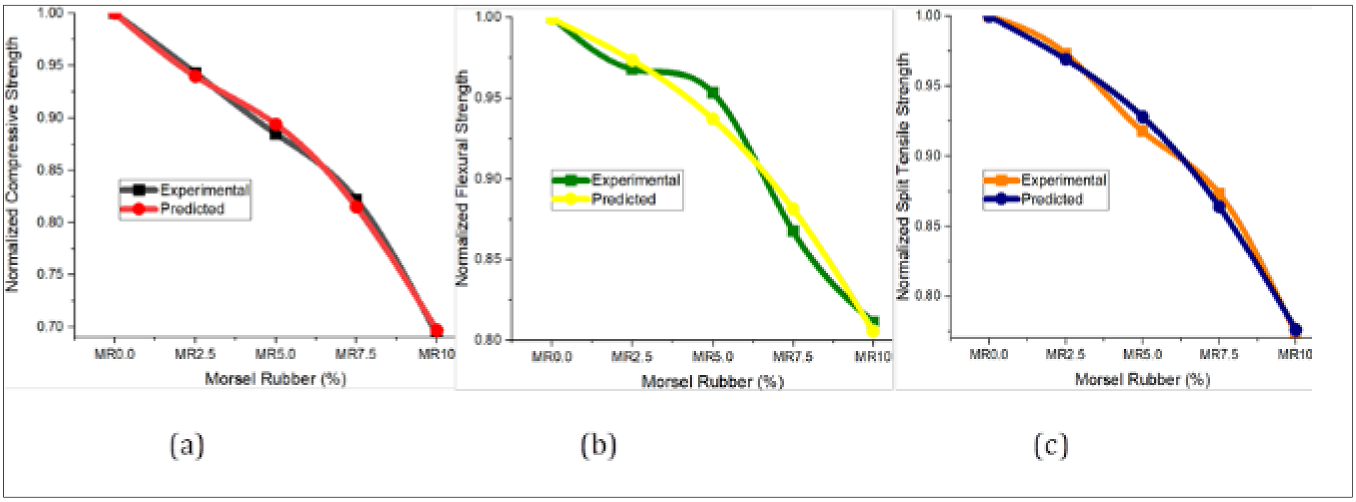

Figure 6 Normalized experimental and predicted data for (a) compressive strength, (b) flexural strength, and (c) split tensile strength of 0 to 300 µ Morsel rubberized concrete

300 - 600 µ

Compressive strength

$$-0.343 \times \left(\frac{MR(\%)}{10}\right)^2 + 0.289 \times \left(\frac{MR(\%)}{10}\right)^1 - 0.205 \times \sqrt{\left(\frac{MR(\%)}{10}\right)} + 1.000$$

Flexural strength

$$- 0.133 \times \left(\frac{MR(\%)}{10}\right)^2 - 0.014 \times \left(\frac{MR(\%)}{10}\right)^1 - 0.006 \times \sqrt{\left(\frac{MR(\%)}{10}\right)} + 0.999$$

Split tensile strength

$$- 0.124 \times \left(\frac{MR(\%)}{10}\right)^2 - 0.063 \times \left(\frac{MR(\%)}{10}\right)^1 - 0.001 \times \sqrt{\left(\frac{MR(\%)}{10}\right)} + 1.000$$

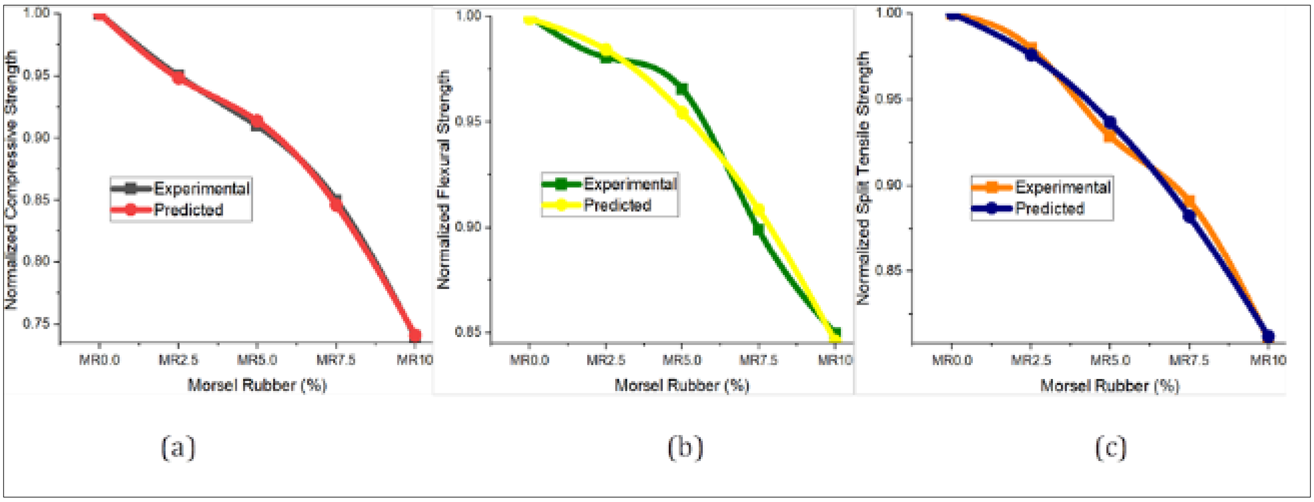

Figure 7 Normalized experimental and predicted data for (a) compressive strength, (b) flexural strength, and (c) split tensile strength of 300 to 600 µ Morsel rubberized concrete

600 – 1180 µ

Compressive strength

$$-0.368 \times \left(\frac{CR(\%)}{10}\right)^2 + 0.263 \times \left(\frac{CR(\%)}{10}\right)^1 - 0.119 \times \sqrt{\left(\frac{CR(\%)}{10}\right)} + 1.000$$

Flexural strength

$$0.032 \times \left(\frac{CR(\%)}{10}\right)^2 - 0.331 \times \left(\frac{CR(\%)}{10}\right)^1 + 0.205 \times \sqrt{\left(\frac{CR(\%)}{10}\right)} + 1.000$$

Split tensile strength

$$- 0.016 \times \left(\frac{CR(\%)}{10}\right)^2 - 0.152 \times \left(\frac{CR(\%)}{10}\right)^1 + 0.065 \times \sqrt{\left(\frac{CR(\%)}{10}\right)} + 1.000$$

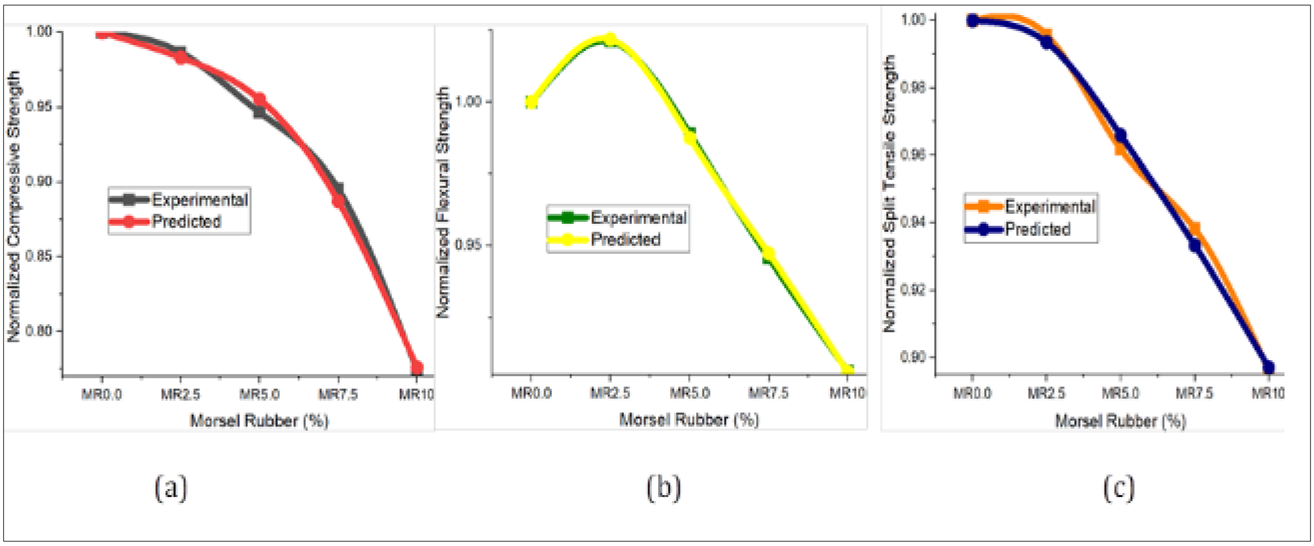

Figure 8 Normalized experimental and predicted data for (a) compressive strength, (b) flexural strength, and (c) split tensile strength of 600 to 1180 µ Morsel rubberized concrete

4. Conclusion

The study reveals that increasing morsel rubber content in concrete reduces its compressive strength, with reductions becoming more significant at higher substitution levels. Specifically, compressive strength declines by 5.70% to 30.76% for MRd1, 5.01% to 26.01% for MRd2, and 1.34% to 22.65% for MRd3 when the rubber percentage increases from 2.5% to 10%. Flexural strength also generally decreases with higher morsel rubber content, though MRd3 shows a unique increase at a 2.5% substitution level, reaching a maximum of 4.75 MPa after 28 days, potentially due to rubber fiber effects. Overall, rubberized concrete offers improved resistance to sudden cracking under bending.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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