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RESEARCH ARTICLE

Experimental evaluation and ANN-based predictive modelling of sand-coated rubberized concrete for sustainable construction

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Abstract

The study is focused on to utilise sand-coated rubber shreds as a partial replacement for coarse aggregate in normal strength concrete (NSC), with the aim that it will improve the performance of rubberized concrete and reduce environmental waste. Whereas traditional rubber aggregates have weak bonds with cementitious materials, resulting in limited strength development of the concrete, sand-coated rubber shreds were used with the intention of increasing their adhesion through the novel coating technique. Concrete with different proportions of sand coated rubber (0%, 2.5%, 5%, and 7.5%) were tested for mechanical and durability properties such as compressive strength, flexural strength, toughness, elasticity, water absorption, resistance to acid, and chloride permeability. Findings reveal that rubber replacement of up to 5% improves the strength and durability of the concrete. The mix with 5% replacement (M2) from the experiment recorded the highest compressive strength of 29.31 MPa and flexural strength of 8.93 MPa. A General Regression Neural Network (GRNN) model was developed in MATLAB to predict performance parameters. Prediction of the GRNN model was very close to experimental values, thus making the model a good tool to predict the behaviour of rubberized concrete. This implies that sand-coated rubber aggregates provide a solution to the problem of sustainability with better concrete performance and utilizes rubber waste as a resource. The GRNN model acts as a good predictive tool to enhance the commercial use of rubberized concrete.

Keywords Rubberized concrete · Sand-coated rubber shreds · GRNN · ANN prediction · Sustainable construction · Durability · Mechanical properties

1 Introduction

Industrialization and urbanization happening at a fast pace have witnessed equally exponential increases in the generation of non-biodegradable wastes, especially scrap rubber tires. With global-level estimates showing that more than one billion tires get disposed of annually, these become a grave threat to the environment as they are resistant to natural degradation processes. This has prompted research workers and engineers to look for the reuse of this waste, especially in construction, where rubber shreds are used in concrete in place of natural aggregate materials. Rubberized concrete offers a handful of advantages like resisting impact, absorbing energy, and ductility, but probably the added rubber decreases the concrete compression and flexure. Such behaviour arises from the poor interfacial bonding between hydrophobic rubber surfaces and hydrophilic cement paste. Many surface modifications have been considered to enhance the interface. Among these, the sand-coating has been established as one treatment that enhances the ITZ at the rubber-cement interface and thereby the mechanical behaviours [1, 2].

Being able to predict mechanical performance in rubberized concrete has remained very difficult owing to the complexity of interaction between material constituents and variability in the test results. Conventional empirical methods could fail when confronted by nonlinear relationships among variables. Recently, various modelers have applied Artificial Neural Networks (ANN), especially General

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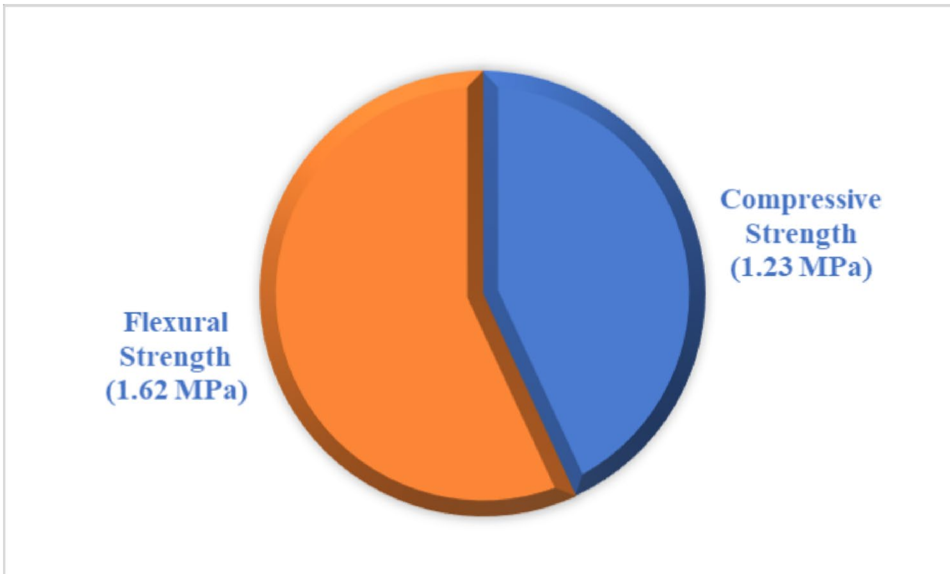

Fig. 11 Root Mean Square Error (RMSE) Summary

(GRNN). The summary of the notable findings of this comprehensive research is as follows:

- Mix Design and Density Trends: The use of rubber shreds coated with sand contributed to a decrease in the overall dry concrete density, which is effective lightweighting, without compromising the desired mechanical properties. The density dropped from 2834 kg/m³ in the control mix (M0) to 2622 kg/m³ in the highest content of rubber blend (M3).
- Mechanical Performance: Compressive strength improved with the inclusion of rubber shreds to 5% to a high average of 29.31 MPa at M2 before reducing steadily at 7.5% replacement. Flexural strength also improved significantly, particularly in mixes containing rubber percentages of 2.5% and 5%, to a high of 8.93 MPa at M2. This is because of enhanced crack bridging and elasticity of rubber particles.
- Least strength loss in acid conditions was seen with the M2 mix, reflecting greater chemical resistance to an optimal rubber level. The rubberized mixes were all more permeable than control, and M2 still had a good mechanical strength-durability compromise.Rubberized mixes were more impact resistant, as M2 took 20 blows to achieve final failure, consistent with greater toughness.
- GRNN modeling made satisfactory predictions in compressive strength as well as flexural strength. Differentials between experimental and predicted values were maintained within tolerance limits (±10% for compressive strength, ±15% for flexural strength), testifying to the viability of GRNN prediction in predicting challenging non-linear problems in civil engineering material science research.

Together, these results confirm that adding sand-coated rubber shreds to concrete not only improves certain mechanical and impact characteristics but also contributes to environmental sustainability in a positive way through recycling recycled rubber.

5 Conclusion

This research examined partial replacement of coarse aggregate with sand-coated rubber shreds in concrete based on its mechanical, durability, and environmental behavior. The results of this research are useful in giving insights on the potential of using rubberized concrete as a new material in sustainable building. The main conclusions of this research are:

- Compressive and flexural strengths up to 5% of rubber shreds were improved. The optimal combination, M2 (5% rubber replacement), was determined to possess a compressive strength of 29.31 MPa and a flexural strength of 8.93 MPa, both greater than that of the control mix (M0). It indicates that moderate rubber addition improves the mechanical performance of concrete, especially in terms of energy absorption and crack-bridging, which are most pertinent to application under dynamic and impact loading conditions.
- Rubber incorporation lowered the dry density of the concrete, which would be characteristic of its ability to form lightweight concrete. This aspect can be especially useful in non-structural applications, such as pavements or light partition walls, where dead load is minimized without loss of performance.
- The durability tests indicated that rubberized concrete had good resistance to acid and impact load, particularly in

mixes with up to a maximum of 5% rubber content. Mix M2 was seen to have improved acid resistance and low loss of strength. Higher rubber content did result in poorer chloride resistance. However, the rubberized mixes showed improved impact resistance, indicating that rubber-modified concrete may prove to be highly beneficial in structures exposed to dynamic loads and abrasion.

- General Regression Neural Network (GRNN) was able to predict the compressive and flexural strengths of the rubberized concrete in an acceptable range of errors (± 10% for compressive strength and ± 15% for flexural strength). This demonstrates the applicability of machine learning models to optimize concrete mix design and predict material performance, presenting a good alternative to experiment-based methods.
- Sand-coated rubber shreds is a viable method for waste rubber recycling, the reduction of environment pollution, and the preservation of natural aggregates. This paper provides evidence to support the assertion that rubberized concrete can be part of circular economy practices in the construction sector as a sustainable solution for waste management and material resource management.

Overall, this research is compelling proof that rubberized concrete can be a viable alternative to normal concrete, particularly in non-structural applications, where all its benefits of light weight, impact resistance, and sustainability can be maximized. Its application as high-performance structural elements, however, requires further research to improve chloride resistance and assess long-term performance.

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Declarations

Conflict of interest The authors declare no competing interests.

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