COMPDYN 2025
10th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, M. Fragiadakis (eds.)
Rhodes Island, Greece, 15-18 June 2025

MECHANICAL PERFORMANCE OF COMPOSITE SLABS WITH RECYCLED CONCRETE AGGREGATES: THE SARCOS PROJECT

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Abstract

The urgency to reduce the environmental impact of concrete structures is widely recognized, with the consumption of natural aggregates being a significant concern due to the need for new quarries. Recycled concrete aggregates (RCA) derived from construction and demolition waste offer a viable solution. Composite slabs, made of concrete over a steel sheet, present multiple benefits over traditional slabs, including faster construction, enhanced strength, and environmental advantages. This study examines the mechanical performance of 48 composite slabs with RCA replacement levels ranging from 0% to 100%, across three span lengths (2.4 m, 2.8 m, 3.2 m). Four-point bending tests were conducted, focusing on load-bearing capacity and interface bond strength. Results indicate that slabs with RCA demonstrate structural performance comparable to those without RCA, highlighting its potential as a sustainable construction solution. This research provides insight into optimal RCA levels for composite slabs, balancing sustainability with high mechanical standards.

Keywords: Sustainability, concrete, composite slabs, structures.

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1 INTRODUCTION

The increasing demand for sustainable construction materials has led researchers to explore alternatives that reduce the environmental impact of conventional concrete structures. One of the primary concerns in this domain is the excessive consumption of natural aggregates, which necessitates the exploitation of new quarries, thereby causing ecological degradation and resource depletion [1-3]. Recycled concrete aggregates (RCA), derived from construction and demolition waste, have emerged as a viable solution to address these challenges. Their reuse in structural applications aligns with the principles of circular economy, reducing waste accumulation and minimizing the carbon footprint associated with aggregate extraction and processing.

Composite slabs, consisting of concrete cast over profiled steel sheeting, offer several advantages over traditional reinforced concrete slabs. These include improved strength-to-weight ratio, ease of construction, and enhanced structural performance due to the synergy between the two materials. The integration of RCA into composite slabs has the potential to further enhance their sustainability; however, there remains limited knowledge regarding the impact of RCA on their mechanical behavior, particularly in terms of load-bearing capacity, flexural response, and bond strength at the concrete-steel interface.

Previous studies, see [4 - 5] have shown that while RCA-based concrete exhibits slightly reduced compressive strength compared to natural aggregate concrete, it can enhance interfacial bonding due to its rougher surface texture . Nevertheless, the implications of these characteristics on the global performance of composite slabs remain underexplored. Current research, see [6], has primarily focused on standalone recycled aggregate concrete elements, with insufficient attention given to composite structural systems that incorporate RCA. Additionally, there is a lack of experimental data on the effect of varying RCA replacement levels in composite slabs under flexural loading conditions.

This paper addresses these gaps by presenting an experimental investigation on the mechanical performance of composite slabs incorporating RCA at different replacement levels (0%, 20%, 30%, 50%, 70% and 100%) across three span lengths (2.4 m, 2.8 m, and 3.2 m). The study evaluates the collapse load, interface bond strength, and structural behavior under four-point bending tests. The results provide insights into the feasibility of using RCA in composite slabs without compromising structural integrity, contributing to the ongoing efforts to promote sustainable construction practices.

The structure of this paper is as follows: Section 2 presents the materials and methods, including details on the experimental setup, mix designs, and testing procedures. Section 3 discusses the results obtained from the experimental campaign, focusing on the mechanical performance of the tested slabs. Section 4 provides an analysis of the observed failure mechanisms and implications for structural design. Finally, Section 5 concludes the study by summarizing key findings and outlining future research directions in the field of sustainable composite construction.

2. MATERIALS AND METHODS

2.1 Materials

The experimental campaign involved the fabrication and testing of composite slabs composed of a profiled steel sheeting and concrete with varying levels of recycled concrete aggregate (RCA) replacement. The key materials used in this study include: a Portland limestone cement (TECNOCEM A-LL 42.5 R) was used to ensure consistency in mix performance across all specimens, coarse and fine aggregates were obtained from a local quarry for natural aggregates, while recycled aggregates were sourced from construction and demolition waste. the maximum aggregate size was 12.5 mm for coarse aggregates and 5 mm for fine aggregates.

Cold-formed steel sheeting (Spinelli SG110-600) with a thickness of 0.75 mm was employed to form the composite slabs. The steel had a mean yield strength of 338.18 MPa and an ultimate strength of 593.16 MPa. A superplasticizer was incorporated in all concrete mixes to enhance workability and achieve the target water-to-cement ratio of 0.51.

2.2 Concrete Mix Design

Four different concrete mix designs were developed to investigate the effect of RCA replacement on the mechanical performance of composite slabs. The RCA replacement levels considered were 0%, 30%, 50%, and 100%. Each mix maintained a constant water-to-cement ratio of 0.51, and all aggregates were pre-saturated to minimize absorption effects. The mix proportions for each design are detailed in Table 1.

ID	**Cement (kg/m³)**	**Water/Cement**	**Fine Aggregate (%)**	**Coarse Aggregate (%)**
M0	366	0.51	0	0
M20	366	0.51	20	20
M30	366	0.51	30	30
M50	366	0.51	50	50
M70	366	0.51	70	70
M100	366	0.51	100	100

Table 1 Mix proportions for each mix.

2.3 Specimen Preparation

A total of 48 composite slabs were fabricated, corresponding to 12 slabs for each of the primary mix designs: M0, M20, M70, and M100. In addition, 3 supplementary slabs were prepared for mix designs M0, M30, M50, and M100 to expand the experimental database. All slabs were cast using three different span lengths: 2.4 m, 2.8 m, and 3.2 m. The profiled steel sheeting was first placed inside the formwork, and concrete was then poured over it to ensure full composite action. After casting, all specimens were cured under controlled laboratory conditions for 28 days before testing.

Figure 1 From left to right sequence of composite slabs preparation.

2.4 Testing Procedure

All specimens were tested under four-point bending conditions, see Figure 2, using a universal testing machine with a 3000 kN capacity. The loading protocol involved two preloading cycles up to 30% and 50% of the estimated collapse load, followed by continuous loading until failure. Linear variable displacement transducers (LVDTs) were positioned at key locations to monitor midspan deflection and interfacial slip.

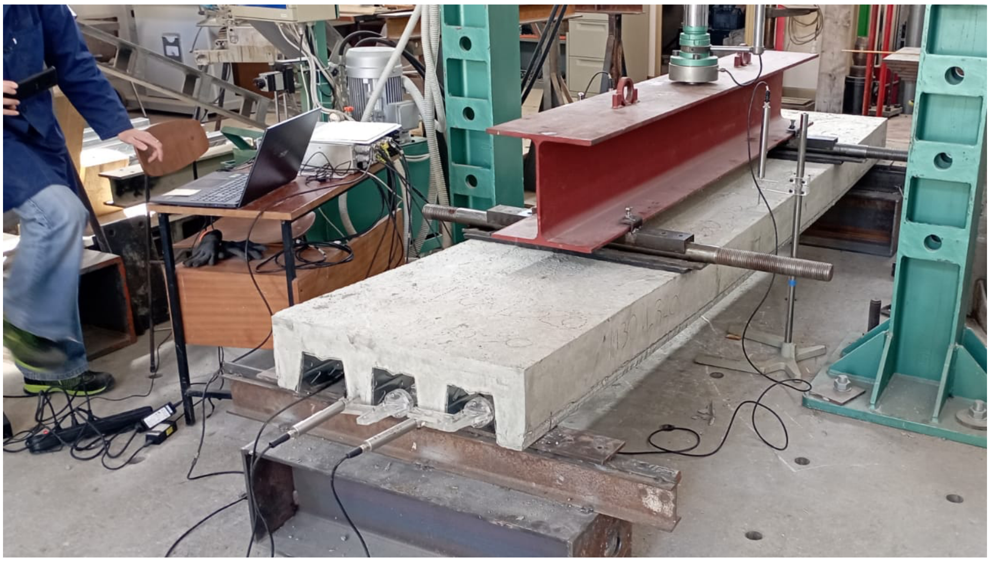

Figure 2 Four point bending test for composite slabs.

To monitor structural response, eight linear variable displacement transducers (LVDTs) were installed per slab. These included four LVDTs positioned at midspan and under each load point to measure vertical displacements, and four additional LVDTs mounted laterally to capture interfacial slip (debonding) between the steel sheeting and the concrete layer. The LVDTs had a resolution of 1 μm, nominal sensitivity of 2 mV/V, and a nominal displacement capacity of 100 mm. The measured quantities allowed for the characterization of both global flexural response and local bond behavior, enabling a detailed understanding of load-deflection curves and debonding initiation.

The collapse of each slab was characterized by a sudden drop in load following interfacial failure, succeeded by a ductile phase governed by flexural cracking and load redistribution. This behavior confirmed the structural redundancy of the system and allowed for the calculation of longitudinal shear strength in accordance with EN 1994-1-1 [7]. See [8] for more details.

3. RESULTS AND DISCUSSION

3.1 Concrete compressive strength

Table 2 presents the 28-day compressive strength values for six different concrete mix designs with varying percentages of recycled concrete aggregate (RCA). The reference mix M0 (0% RCA) shows an average strength of 38.2 MPa, serving as a benchmark for performance comparison.

Interestingly, M20 maintains a nearly identical strength (38.1 MPa) with a significantly lower standard deviation (0.67 MPa), indicating consistent performance even with 20% replacement of both fine and coarse aggregates. M70 unexpectedly reaches the highest strength

(39.9 MPa), suggesting that at certain replacement ratios, the RCA might enhance internal friction or benefit from better particle packing. However, M30, M50, and M100 exhibit reductions in strength relative to the control mix, with M30 and M100 dropping to approximately 32–33 MPa, confirming the known detrimental effect of high RCA content on mechanical performance.
It is also worth noting that the standard deviation is higher for mixes with increased RCA content (e.g., M50 and M100), suggesting greater variability likely due to the heterogeneous nature of recycled aggregates. Overall, the data reinforce that moderate RCA substitution (up to 20%) can be adopted without compromising strength, while higher percentages require careful optimization to mitigate the mechanical drawbacks associated with RCA.

Mix	**Avg (MPa)**	**Std Dev (MPa)**
M0	38.2	1.40
M20	38.1	0.67
M30	32.3	0.80
M50	34.5	1.65
M70	39.9	1.56
M100	32.9	1.43

Table 2 Compressive strength at 28 days for different concrete mixes.

3.2 Collapse mechanism

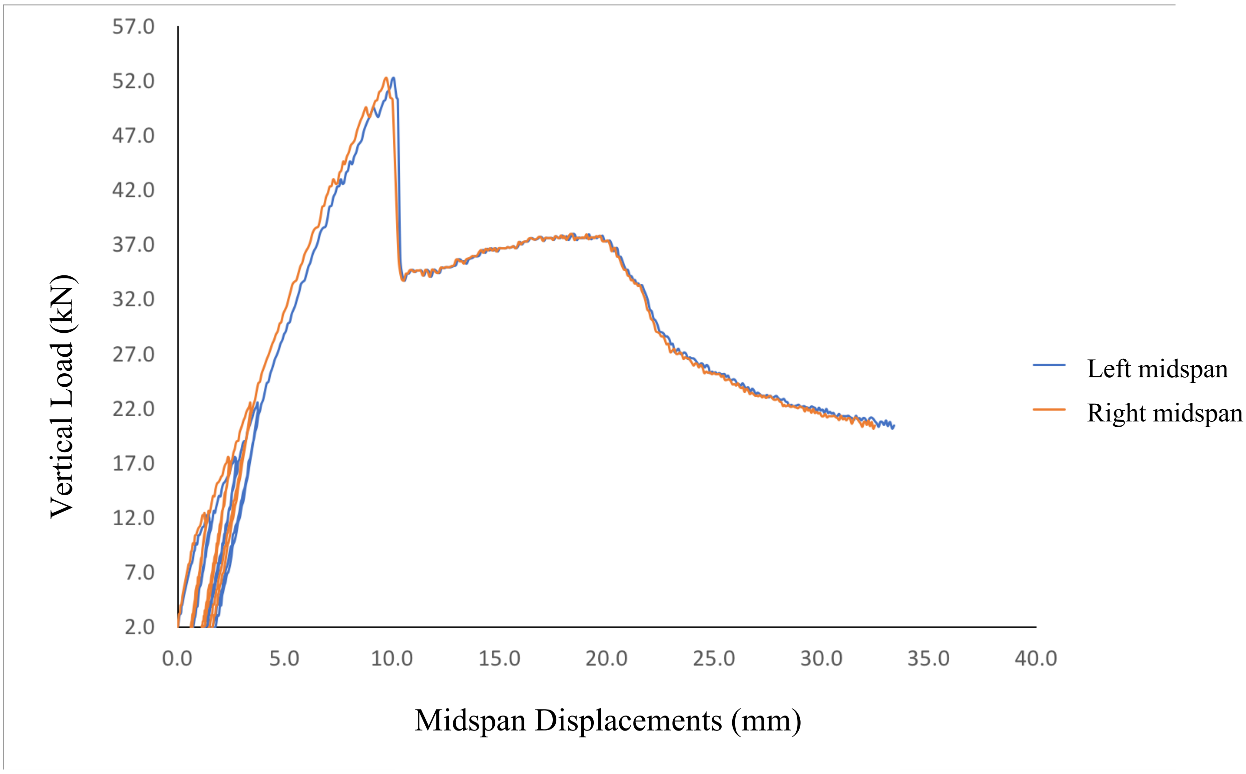

Figure 3 Load -midspan displacement 280 cm span length for M50 mix.

Figure 3, reporting the vertical load vs. midspan deflection, demonstrates a typical ductile failure mechanism for composite slabs with recycled concrete aggregates. The system exhibits good energy dissipation capacity, with the initial debonding failure followed by a stable post-peak behavior, confirming the structural robustness of the tested configuration.
The two curves correspond to measurements taken by two LVDTs placed at midspan—one in the right and one in the left position to capture possible asymmetries or local effects during testing.

At the Initial Linear Phase (0–8 mm deflection) both curves show a linear elastic response, where the slab behaves as a fully bonded composite section. The load increases steadily up to approximately 50–52 kN.

The peak load (~52 kN at ~9–10 mm deflection) corresponds to the onset of debonding between the steel sheeting and the concrete. This sudden event is evidenced by the abrupt drop in load, which is characteristic of interface failure. After the sudden drop, the curves enter a plateau region, where the load stabilizes around 33–35 kN despite increasing deflection. This indicates that the composite action is partially lost, but the slab still resists additional deformation through flexural redistribution and residual bonding.

Beyond 20 mm deflection, the curves exhibit a gradual decrease in load, associated with flexural cracking, progressive bond degradation, and plasticity in the steel deck. More information and results can be found in [8].

3.3 General trends of the collapse load

The general trend of the experimental results highlight the mechanical performance of composite slabs incorporating recycled concrete aggregates (RCA) under four-point bending tests with span lengths of 2.4 m, 2.8 m, and 3.2 m, respectively is reported in Figure 4, Figure 5 and Figure 6.

Figure 4, presenting collapse load of 240 cm span slabs, shows that slabs with RCA replacement levels up to 50% maintain comparable load-bearing capacity to the control slabs (0% RCA). A marginal reduction in peak load is observed at 70% RCA, while a more pronounced decrease is evident at 100% RCA. This suggests that partial RCA substitution can be implemented without substantial performance loss.

Figure 5, showing collapse load of 280 cm span slabs, reveals a similar trend, with RCA-based slabs displaying a slight decline in ultimate load as replacement levels increase. The 30% and 50% RCA mixtures perform almost equivalently to the control specimens, confirming the viability of intermediate RCA levels in structural applications. However, 100% RCA specimens show a significant reduction in strength, likely due to the lower stiffness and increased porosity of RCA aggregates, as reported in previous studies (Faleschini et al., 2016; Vijerathne et al., 2024).

Figure 6, reporting the collapse load of 320 cm span slabs, indicates that at the longest span, the impact of RCA content becomes more pronounced. While slabs with up to 50% RCA sustain acceptable load levels, those with 70% and 100% RCA exhibit a marked drop in collapse capacity, reinforcing the importance of optimizing RCA proportions to balance sustainability and structural integrity.

These findings confirm that RCA can be effectively integrated into composite slab systems, provided that replacement ratios are carefully selected. The results align with prior research on RCA-based concrete structures (Ghanbari et al., 2018), underscoring the potential of RCA in sustainable construction while highlighting the need for strategic mix design adjustments to mitigate performance reductions at high RCA levels.

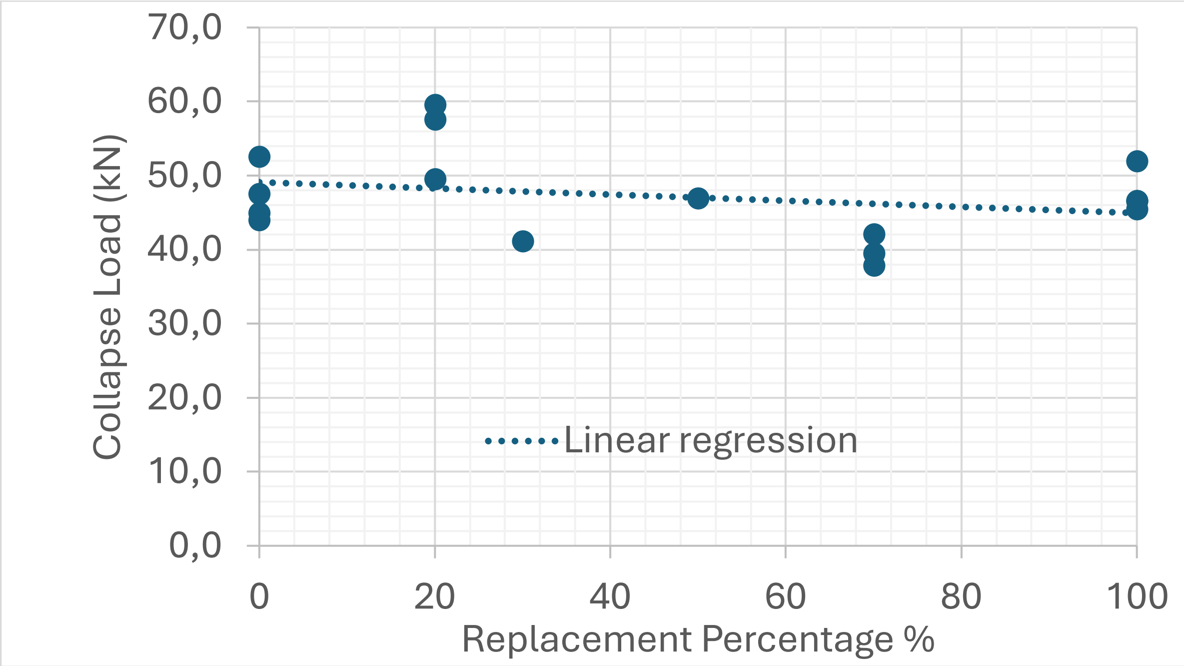

Figure 4 Collapse load of composite slabs with 240 cm span length.

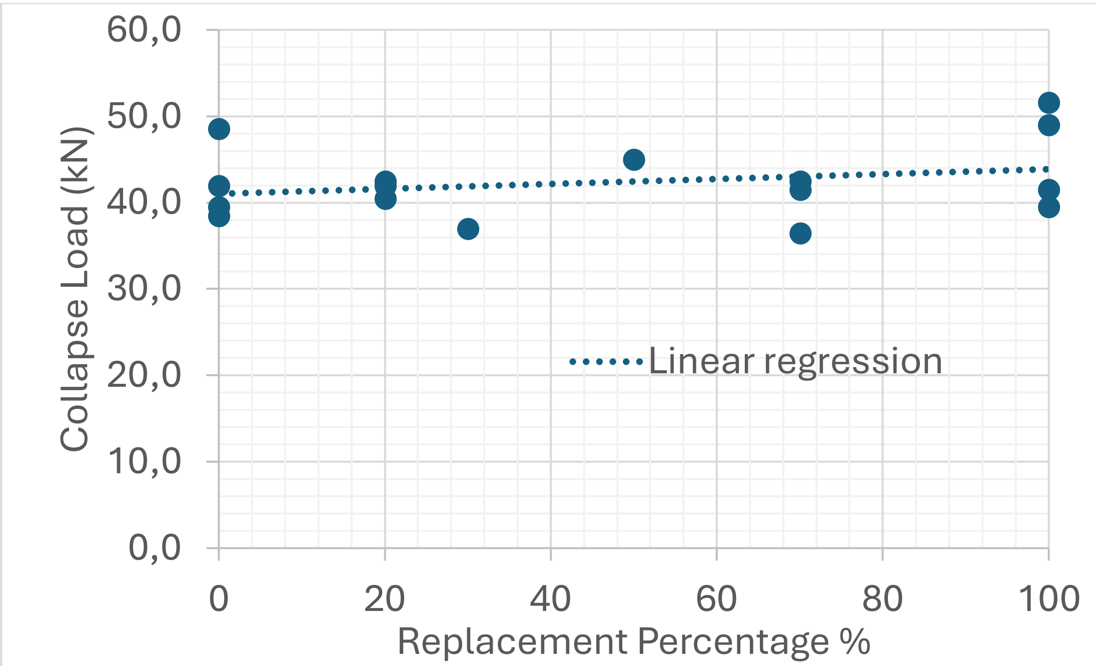

Figure 5 Collapse load of composite slabs with 280 cm span length.

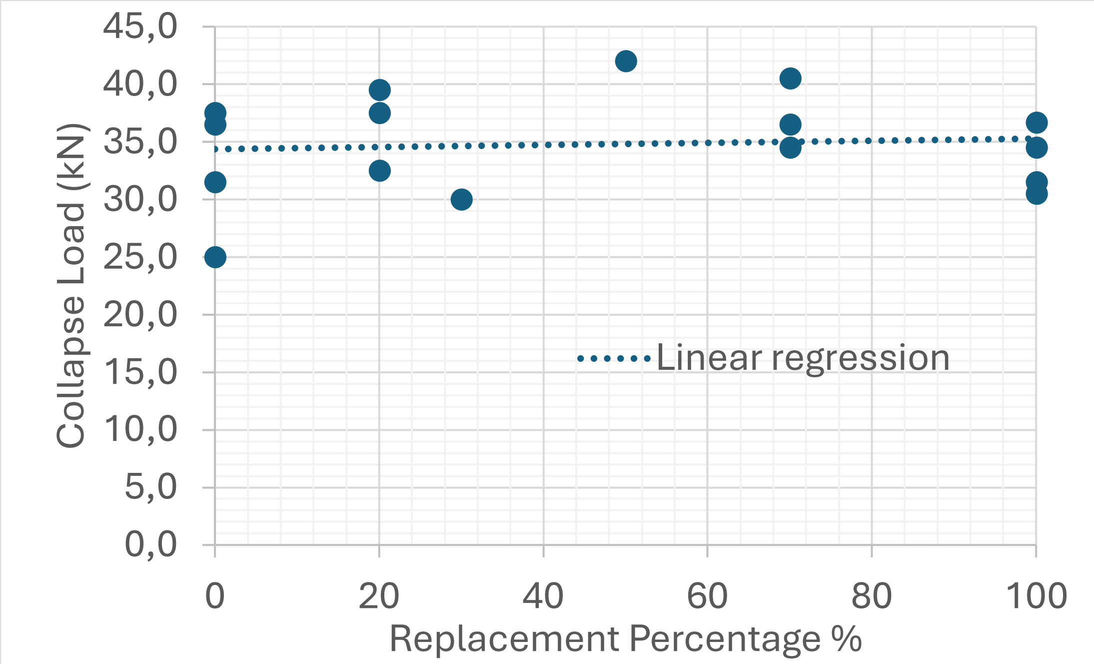

Figure 6 Collapse load of composite slabs with 320 cm span length.

The mechanical performance of composite slabs incorporating recycled concrete aggregates (RCA) can be attributed to a combination of physical and chemical factors that influence the bond between the concrete matrix and steel reinforcement. One key factor is the improved surface roughness of RCA particles, which are typically more angular and textured than natural aggregates. This increased roughness enhances the mechanical interlocking with steel reinforcement, contributing to a more effective load transfer.

Additionally, increased concrete porosity in RCA-based mixtures plays a dual role. While excessive porosity can reduce mechanical strength, the presence of microvoids may also enhance the bond by promoting a more extensive interfacial contact area between the concrete and reinforcement. This effect is particularly beneficial at moderate RCA replacement levels, where the increased bonding compensates for minor reductions in compressive strength.

Furthermore, enhanced chemical interactions between RCA and the steel reinforcement can improve the overall bond strength. Surface treatment processes such as washing and curing can modify RCA properties, promoting a more uniform and reactive interface. This chemical refinement strengthens the adhesion between the concrete matrix and steel reinforcement, particularly in well-designed RCA mixtures.

These combined effects explain why composite slabs with up to 50% RCA maintain structural performance comparable to conventional slabs. However, at higher RCA content, the negative impact of increased porosity and reduced stiffness becomes more significant, leading to a decline in load-bearing capacity. These findings highlight the importance of optimizing RCA proportions and processing methods to balance sustainability and mechanical efficiency in composite slab applications.

5. CONCLUSION

This study investigated the mechanical performance of composite slabs incorporating recycled concrete aggregates (RCA) through a comprehensive experimental campaign involving 48 specimens with varying RCA replacement levels and span lengths. The findings demonstrate that partial replacement of natural aggregates with RCA—up to 50%—allows for maintaining mechanical performance that is comparable to traditional composite slabs. In particular, mixes with 20–50% RCA showed similar or only marginally reduced compressive strength and collapse load, confirming their viability for structural use.

At higher replacement levels (e.g., 100%), the mechanical performance deteriorated, with compressive strength dropping to 32.9 MPa and collapse loads significantly lower—especially for longer spans—due to increased porosity and reduced stiffness of the recycled matrix.

The load-deflection behavior consistently exhibited a ductile response, with a sudden drop at the onset of debonding followed by stable post-peak behavior. This reflects good structural redundancy and energy dissipation capacity, particularly relevant for seismic applications.

The performance trends observed are attributed to a combination of physical (increased surface roughness) and chemical (enhanced bond reactivity) mechanisms that improve interface performance between RCA-based concrete and steel sheeting at intermediate replacement levels. Nevertheless, greater variability at high RCA content reinforces the need for optimized mix design and improved quality control of recycled aggregates.

From a sustainability perspective, RCA offers a promising route to reduce environmental impact without sacrificing structural efficiency, supporting circular economy practices in the construction industry.

Looking ahead, future developments could explore the integration of natural fibers, such as jute, into RCA-based concrete, combining recycled aggregates with bio-based reinforcement strategies. Preliminary studies have already shown promising outcomes in terms of mechanical performance and water resistance in jute-reinforced mortars [9-11], opening new paths for fully sustainable composite construction materials.

Acknowledgment

The financial support of project SARCOS PRIN2022 – CUP: F53D23002030006 - Prot. 2022WWN3TC is acknowledged. The authors extend their sincerest thanks to the Spinelli srl Company for providing the steel sheets (named SG110-600) and to Heidelberg Materials for providing the concrete essential for this research.

REFERENCES

1. Faleschini, F., Zanini, M., Pellegrino, C., & Pasinato, S. (2016). Sustainable management and supply of natural and recycled aggregates in a medium-size integrated plant. *Waste management*, 49, 146-155 . https://doi.org/10.1016/j.wasman.2016.01.013.
2. Vijerathne, D., Wahala, S., & Illankoon, C. (2024). Impact of Crushed Natural Aggregate on Environmental Footprint of the Construction Industry: Enhancing Sustainability in Aggregate Production. Buildings. https://doi.org/10.3390/buildings14092770.
3. Ghanbari, M., Abbasi, A., & Ravanshadnia, M. (2018). Production of natural and recycled aggregates: the environmental impacts of energy consumption and CO2 emissions. Journal of Material Cycles and Waste Management, 20, 810-822. https://doi.org/10.1007/S10163-017-0640-2.
4. Lei, B., Liu, H., Yao, Z., & Tang, Z. (2019). Experimental study on the compressive strength, damping and interfacial transition zone properties of modified recycled aggregate concrete. Royal Society Open Science, 6(12), 190813.
5. Lu, C., Yu, Q., Wei, J., Niu, Y., Zhang, Y., Lin, C. & Yang, P. (2024). Influence of interface transition zones (ITZ) and pore structure on the compressive strength of recycled aggregate concrete. Construction and Building Materials, 456, 139299.

6. Li, W., Xiao, J., Shi, C., & Poon, C. S. (2015). Structural behaviour of composite members with recycled aggregate concrete—An overview. Advances in Structural Engineering, 18(6), 919-938.
7. EN 1994-1-1, Eurocode 4: Design of Composite Steel and Concrete Structures Part 1-1, GeneralRules and Rules for Buildings, 2004.
8. Stochino, F., Alibeigibeni, A., Zucca, M., Valdes, M., Concu, G., Simoncelli, M., Pisani, M. & Bernuzzi, C. (2024). Mechanical behavior of composite slabs with recycled concrete aggregates: A preliminary study. In Structures 70, 107838.
9. Stochino, F., Majumder, A., Frattolillo, A., Valdes, M., & Martinelli, E. (2025). Jute fiber reinforcement for masonry walls: Integrating structural strength and thermal insulation in sustainable upgrades. Journal of Building Engineering, 104, 112210.
10. Majumder, A., Stochino, F., Frattolillo, A., Valdes, M., Martinelli, E., & Gatto, G. (2024). Enhancing Sustainability in Construction: Water Effect on Jute Fiber Composite Mortar. Periodica Polytechnica. Civil Engineering, 68(3), 974-986.
11. Majumder, A., Stochino, F., Frattolillo, A., Valdes, M., Gatto, G., & Martinelli, E. (2024). Sustainable Retrofitting Solutions: Evaluating the Performance of Jute Fiber Nets and Composite Mortar in Natural Fiber Textile Reinforced Mortars. Sustainability, 16(3), 1175.