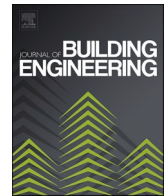




ELSEVIER

Contents lists available at ScienceDirect

Journal of Building Engineering

journal homepage: www.elsevier.com/locate/job

Longitudinal shear behaviour in Recycled Aggregate Concrete Composite Slabs: A state-of-the-art review

Marta Saccone^{a,*}, Flavio Stochino^a, Marco Zucca^a, Marco Simoncelli^b

^a Department of Civil, Environmental Engineering and Architecture, University of Cagliari, Via Marengo 2, Cagliari, 09123, CA, Italy

^b Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Via G. Ponzio, Milano, 20133, MI, Italy

ARTICLE INFO

Keywords:

Recycled aggregate concrete (RAC)
Composite slabs
Longitudinal shear behaviour
Sustainability
Steel-concrete structures
Bonding

ABSTRACT

The environmental challenges posed by concrete production, particularly high carbon dioxide emissions and the extensive use of natural resources, necessitate more sustainable construction practices. Recycled Aggregate Concrete (RAC) offers a promising alternative by reducing waste from construction and demolition activities while conserving natural aggregates. This review investigates RAC integration within composite steel-concrete slabs, emphasizing longitudinal shear behaviour—a crucial factor in structural integrity and load distribution. Through a comprehensive analysis of experimental results and theoretical advancements, this study examines the effects of recycled concrete aggregate replacement ratio, water-to-cement ratio, and steel deck geometry on shear bond strength and overall performance. Advanced analytical methods, such as the m-k method and its adaptations, are reviewed to assess their predictive capabilities and applicability in Recycled Aggregate Concrete Composite Slabs (RACCS). The study identifies critical gaps in the current literature, particularly regarding the combined influence of geometric and material variables on longitudinal shear resistance. The results highlight increased performance variability in RAC systems, primarily due to interfacial degradation and reduced aggregate quality, which compromise the mechanical interlock and friction-based shear transfer mechanism. The review critically evaluates the m-k method and its extensions, showing that while the framework remains applicable, the coefficients m and k are strongly influenced by Recycled Concrete Aggregates (RCA)-related parameters and require physical reinterpretation. Overall, the review concludes that RAC-based composite slabs can achieve satisfactory performance when appropriately designed but require tailored analytical approaches to ensure safety and reliability in structural applications.

1. Introduction

The requirement for landfills has increased with rapid urbanization, which thereby results in waste generation mainly due to debris generated during construction and demolition activities that eventually lead to the loss of land area, followed by the destruction of natural ecosystems [1,2]. Concrete, a composite material consisting of aggregates embedded in a cementitious matrix, has been the most widely utilized construction material since the early 1900s. However, its production poses significant environmental challenges, contributing approximately 8 % of global carbon dioxide emissions [3]. Over the past two decades, cement production worldwide has

* Corresponding author.

E-mail address: marta.saccone@unica.it (M. Saccone).

<https://doi.org/10.1016/j.job.2025.114002>

Received 29 January 2025; Received in revised form 21 August 2025; Accepted 2 September 2025

Available online 4 September 2025

2352-7102/© 2025 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

increased dramatically from 1.10 billion tonnes to 3.27 billion tonnes [4,5]. Furthermore, the extensive extraction of sand required for concrete and glazing production has led to severe ecological degradation, endangering biodiversity and natural habitats [6,7]. To address these environmental concerns, recycled aggregates from concrete demolition waste have emerged as a sustainable alternative. The urgency to adopt recycled aggregates in construction is heightened by the aging infrastructure of buildings constructed during the 1950s and 1960s, especially in post-World War II Europe, many of which are coming to the end of their lifecycle [8]. Within the context of sustainable structure, Recycled Aggregate Concrete (RAC) emerged as an alternative way to save costs on construction and reduce the utilization rate of natural resources and the carbon dioxide emissions during the manufacturing process [9]. However, the replacement of natural aggregates can reduce the mechanical properties of concrete when recycled aggregate is used. This is largely the result of the residual mortar presence on recycled aggregates, which, as natural porous materials, are not universally fully saturated during their life and thus require a surplus of water to achieve a full saturation state. This results in a higher water-cement ratio, which affects the mechanical properties and will lead to lower bond adhesion between recycled aggregates [10–12].

Composite steel-concrete slabs, widely recognized for their established use in civil and industrial structural applications, are defined by ASCE [13] as "a system comprising normal-weight or lightweight structural concrete placed permanently over cold-formed steel decks, where the steel deck serves a dual purpose: acting as formwork during construction and providing positive reinforcement during service." Incorporating Recycled Aggregate Concrete (RAC) into composite steel-concrete slabs offers significant potential for enhancing sustainability in the construction sector, as these slabs are particularly suitable for the lower strength requirements of RAC, though careful evaluation of the impact of recycled aggregates on overall performance remains essential [14]. Composite slabs can experience bending failure and shear damage near the supports, with a distinctive form of failure being longitudinal shear damage caused by slippage between the concrete slab and the steel deck [15]. The interfacial bond behaviour between concrete and steel is crucial in preventing this type of failure [16,17], and the use of Recycled Concrete Aggregates (RCA) significantly affects this bond due to its influence on the mechanical properties of concrete [18]. The shear bond between the steel deck and concrete is a complex nonlinear interaction involving three main bonding mechanisms: chemical, frictional, and mechanical bonds. The *chemical bond* forms when the cement paste adheres to the steel surface, but once it breaks, it can't be restored, leading to slip initiation. The *frictional bond* arises from the normal force acting perpendicular to the steel-concrete interface, and it directly depends on this force. Both the chemical and frictional bonds are affected by the properties of the cement paste, which are modified when using RCA due to an increase in the water-to-cement ratio (w/c), subsequently impacting the mechanical performance of the concrete [19]. The *mechanical bond*, on the other hand, is created by the physical interlocking between the profiled steel sheeting and the concrete, enhanced by surface roughness, indentations, or embossments on the steel surface. These combined mechanisms work together to provide the composite slab with overall longitudinal shear strength [16].

Previous studies have shown that when natural aggregates are completely replaced by RCA, key mechanical properties, such as compressive strength, tensile strength, and elastic modulus, tend to decrease [8,11,20]. Recent investigations have further confirmed the influence of recycled or alternative aggregates on shear behaviour of reinforced concrete elements. Studies have shown that materials such as Multi-Generation Recycled Aggregates (MGRAC), Electric Arc Furnace (EAF) steel slag, and recycled glass powder have shown comparable shear performance to conventional mixes, though increased variability is observed due to changes in interfacial properties [21–23]. The use of nanomaterials and alternative binders, including Nano-TiO₂ and geopolymer matrices, proved to improve strength and shear resistance in sustainable structural applications [24,25].

In light of this, it is essential to understand how RCA influences the bond between steel and concrete in composite slabs [18]. Researchers have developed general theoretical formulas for its calculation. In a pioneering study, Stark [26] conducted experimental investigations on the behaviour of composite slabs, categorizing their responses into brittle and ductile types. Brittle behaviour occurs when the maximum flexural strength is achieved immediately after longitudinal slip failure or shortly after the first slips arise, leading to a sudden load drop. On the other hand, in ductile behaviour, the slab continues to support the load even after initial slips, with increased slab curvature and a loss of alignment between the neutral axes of the profiled steel sheeting and concrete slab. Building on this, the Eurocode (EN 1994-1-1:2004) [27] defined a slab as having ductile behaviour if the ultimate load is at least 110 % of the load at which the first slip occurred. Porter & Greimann [28] introduce a semi-empirical method, known as the $m-k$ method, which calculates the shear capacity of composite slabs using experimental data. Subsequently, Eurocode 4 (EN 1994-1-1:2004) [27] introduced two methods for assessing the longitudinal shear behaviour of composite slabs: the $m-k$ method and the *Partial Shear Connection Method* (PSM). The PSM for longitudinal shear behaviour in composite slabs, as referenced in Eurocode 4 [27], is primarily based on the work of Johnson & Molenstra [29], who developed the theoretical framework for partial shear connection. Additional contributions were made by Oehlers & Bradford [30], focusing on nonlinear shear behaviour and composite mechanics. The $m-k$ method can be applied to both brittle and ductile composite slab behaviour, while the PSM is limited to ductile failures since it uses simple plastic analysis to estimate the slab's flexural capacity. In both methods, longitudinal shear capacity is assessed through full-scale laboratory testing to evaluate slab performance.

Although the longitudinal shear performance of composite slabs is an area of growing interest [31,32], it remains largely unexplored within the broader context of research on Recycled Aggregate Concrete Composite Slabs (RACCS). Current longitudinal shear design methods have been developed and calibrated for Natural Aggregate Concrete (NAC), resulting in a substantial research gap when addressing RACCS. The absence of structured methodologies to optimize the longitudinal shear performance of RACCS constitutes a significant obstacle, especially given the increasing emphasis on sustainable construction materials [33]. In the authors' view, a systematic investigation of these gaps, coupled with an in-depth exploration of the evolving thematic interconnections, is essential. Such efforts have the potential to bring light to less-explored aspects of longitudinal shear behaviour in RACCS, contributing to a more comprehensive and integrated understanding of this critical domain.

This paper examines the few methodologies currently available to evaluate longitudinal shear behaviour in composite steel-

concrete slabs incorporating RAC. By reviewing recent case studies involving RACCS and the associated design approaches, the paper provides a comprehensive overview of the primary factors influencing longitudinal shear bond behaviour when utilizing RCA.

2. Structure and methodological framework

The structure of this review paper is briefly outlined here. Section 3 presents the systematic literature search methodology developed in accordance with the PRISMA guidelines [34]. These guidelines were specifically employed to document and strengthen the scientific robustness of the literature identification and screening process, providing a transparent and reproducible pathway for selecting the most relevant contributions on this topic. The PRISMA approach was applied exclusively to the literature retrieval phase, with the primary objective of mapping the current state-of-the-art on recycled aggregate concrete composite systems, specifically on composite slab applications, and identifying underexplored areas that represent true research gaps. The process began with an exploratory search to capture the broad research landscape, followed by a structured search strategy on the Scopus dataset. Advanced text-mining tools, including the Bibliometrix package [35] in RStudio [36] and SciMat [37], were used to detect keyword co-occurrences, thematic clusters, and research trends, providing a data-driven refinement of the screening process and supporting the objective detection of poorly investigated aspects of longitudinal shear behaviour in RACCS. Building on this structured mapping, sections 4 and 5 review standardized experimental methodologies and theoretical frameworks commonly employed to evaluate longitudinal shear capacity consistent with the Eurocode 4 [27] provision, such as the m - k and the PSM methods, providing the basis for assessing whether available studies meet established design standards. This approach guided the selection of the few experimental investigations discussed in Section 6, which specifically address the influence of recycled aggregate concrete replacement ratio on longitudinal shear bond behaviour and structural performance in composite slabs. A particular focus is placed on the analysis of load-deformation and load-slip curves, which provide valuable insights into the mechanical response and failure mechanisms of composite slabs under varying conditions. Many studies lack standardized testing procedures or are limited to flexural performance analyses, preventing a reliable comparison with the current design frameworks. Finally, section 7 synthesizes modified design methods developed specifically for application to determine the longitudinal shear strength of RACCS and future research directions, emphasizing the need for parametric studies and robust experimental data to close the research gaps identified through this Prisma-guided literature screening. The overall review framework and structure are summarized in Fig. 1, illustrating how a structured PRISMA-based approach enables a scientifically documented selection process and a clear identification of research gaps in this emerging field.

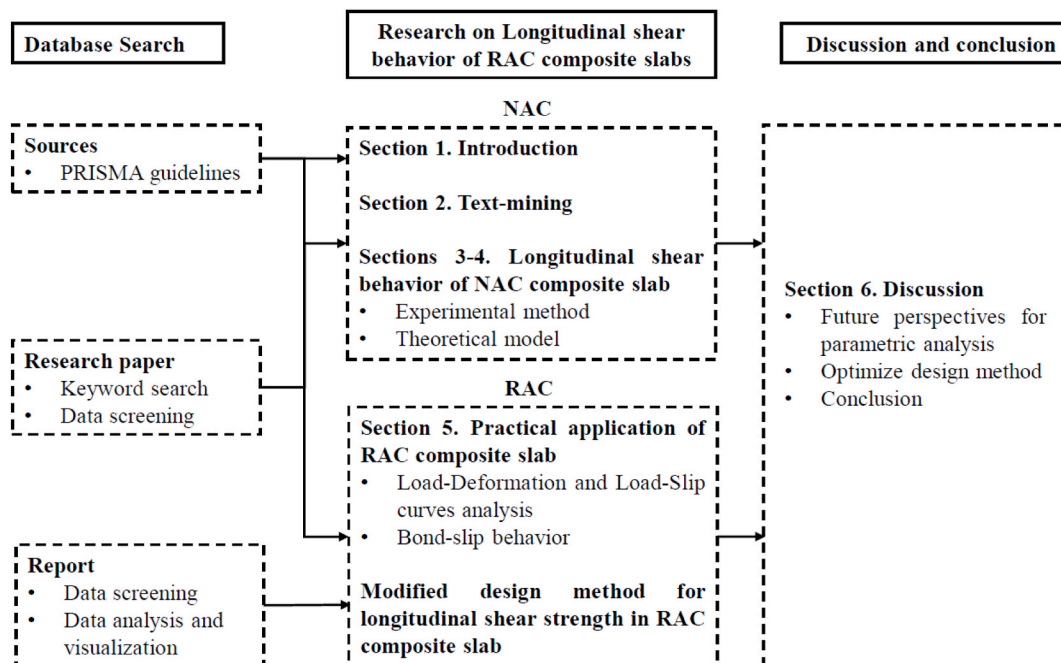


Fig. 1. Research framework of this review.

3. Text-mining

The longitudinal shear behaviour of Recycled Aggregate Concrete Composite Slab (RACCS) was explored through a structured literature review aimed at identifying, mapping, and analysing the most relevant scientific contributions on this emerging topic. The literature search was conducted to identify relevant research articles, reports, and publications, providing a structured understanding of the state-of-the-art in this field. This review adopted a systematic methodology following PRISMA guidelines [34], ensuring thoroughness and replicability. Advanced tools such as the *Bibliometrix* package [35] in RStudio [36] were utilized to facilitate quantitative analysis and text-mining, while the *biblioshiny* module identified high-impact research themes. Additionally, *SciMat* [37] was employed for keyword co-occurrence analysis, enabling the visualization of interrelationships and thematic developments within the research domain. An initial broad search was carried out to explore the general landscape of research concerning RACCS, without applying a strict filter or predefined keywords. This preliminary phase of the literature search, conducted using the Scopus database, initially yielded 90 articles and allowed for the identification of relevant terminology, recurring research patterns, and major thematic directions. Based on the insights gained from the initial exploratory step, a more structured search strategy was developed to systematically retrieve studies directly addressing the longitudinal shear behaviour of RACCS. Following the PRISMA guidelines, the eligibility criteria were defined to include only peer-reviewed journal articles and conference proceedings published between 2009 and 2024. No restrictions were applied regarding language or study design, allowing for the inclusion of both experimental and theoretical-analytical investigations, provided that the studies focused on RAC, RACCS, or explicitly addressed their longitudinal shear performance and composite interaction mechanisms. The selection process followed a two-step screening approach. First, a refined keyword-based filter was applied, followed by a manual screening of titles and abstracts to exclude documents unrelated to the topic or falling outside the intended scope. The keyword-based filtering strategy was developed after the initial scoping phase and included combinations such as (“recycled concrete aggregate”), (“composite slab”), (“concrete slab”), and combined terms like (“recycled aggregate”) and (“concrete aggregate”), to capture literature specifically related to structural applications of recycled aggregates in composite systems. To ensure disciplinary consistency, the search results were restricted to the “Engineering” subject area and sorted by relevance. The data charting process was designed to systematically collect and organize relevant information from each included study. Full bibliographic records were exported from Scopus and processed using a simple home-made spreadsheet. For each document, a set of variables was recorded to support both bibliometric profiling and thematic synthesis. The data items collected included authors, title, year of publication, source and document type, number of citations, publisher, authors’ affiliations, abstract, and both authors and indexed keywords. As previously mentioned, the initial query yielded 90 documents, which were subsequently refined through the application of the chosen criteria and filter steps. Following the removal of duplicates and the exclusion of records not aligned with the keyword strategy or not classified within the “Engineering” subject area, a total of 43 studies were retained for inclusion, as summarized in Table 1. This filtering process ensured a targeted focus, identifying the nuances of longitudinal shear behaviour in RACCS while maintaining broad thematic coverage. Moreover, the adopted methodological pathway not only enable the systematic selection of relevant studies, but also provide insight into the current research direction, highlighting the extent to which the literature addresses RAC and composite structures, and revealing whether the specific topic of RACCS and their longitudinal shear performance has been adequately investigated or still represents an emerging area of study.

Fig. 2 illustrates the trend in publications and average citations per year from 2009 to 2024, providing an overview of the evolution of scientific production and its corresponding impact. The analysis was performed using the *Bibliometrix* package [35] in RStudio [36] based on data retrieved from the Scopus database. The time window was set to include all documents published between 2009 and October 2024. Average citations per year were determined by dividing the average number of citations received by articles published in that specific year by the number of years the article has been citable, i.e., the time elapsed from their publication up to the current year. This approach normalizes the impact of articles based on the time available for accumulating citations. Between 2009 and 2014, the number of publications was minimal, likely reflecting the early stages of research on the analyzed topics. From 2015 onwards, there was a steady increase in publications, with significant peaks in 2022 and 2024, indicating growing attention to the field. However, the trend in average citations per year follows a different trajectory, with a maximum peak recorded in 2019. This does not necessarily reflect greater scientific relevance or innovation in the field during that year but rather the fact that only one article was published in 2019, which received many citations, disproportionately influencing the metric. In more recent years, such as 2023 and 2024, the average citations per year are lower. This phenomenon can be attributed to the fact that recently published articles have had less time to accumulate citations, as the number of citable years is limited. However, it is important to note that even if these articles gain more citations in the future, their average citations per year may not necessarily increase proportionally. This is because, as the number of citable years increases, the denominator grows, and if the growth in citations is not sufficient to offset this, the average value may remain low or even decrease. Another notable observation arises when comparing 2018, 2020, and 2021, which have the same number of publications per year but significantly different average citations per year. Specifically, the average citations per year for 2020 and 2021 are higher than those for 2018, despite articles published in 2018 having had more time to accumulate visibility and citations. This might seem counterintuitive but highlights an important aspect: the growing relevance of the field in recent years. Articles published in 2020 and 2021 likely received more immediate recognition due to increasing interest in the topic within the scientific community, reflecting greater attention to the subjects addressed. In contrast, articles from 2018, despite having a longer citation window, did not generate the same level of impact, suggesting that the field had not yet reached the level of relevance observed in subsequent years. This analysis highlights that there is no direct correlation between the number of publications and their impact in terms of citations. It also emphasizes that the average citations per year are influenced not only by the time elapsed since publication but also by the scientific community’s interest in the topic, as well as the quality and visibility of the articles themselves. This demonstrates the importance of evaluating not solely the quantity of publications but also the temporal context and the specific impact of

Table 1
Dataset of scientific paper retrieved from Scopus.

Authors	Title	Year	Reference
Bicher, B.	Concrete-Filled Steel Tubes (CFT): Innovative composite construction method facilitated by high-performance superplasticizer technology.	2009	[38]
Yao, Q., Yu, X., Zhang, Y., Huang, W.	Mechanical characteristics and seismic performance of multi-rib slab wall.	2009	[39]
Zhang, J.-W., Zhu, Y.-T., Cao, W.-L., Dong, H.-Y.	Flexural behavior of the recycled aggregate concrete composite slabs with closed-section steel deck.	2014	[40]
Coppola, B., Di Maio, L., Courard, L., Scarfato, P., Incarnato, L.	Lightweight cementitious mortar made with foamed plastic waste aggregates.	2015	[41]
Lí, W., Xiao, J., Shi, C., Poon, C.S.	Structural behaviour of composite members with recycled aggregate concrete - An overview.	2015	[42]
Zhang, J., Liu, F., Kazoza, E., Cao, W.	Experimental study on flexural behavior of recycled coarse aggregate concrete composite beams with closed-section steel deck.	2015	[43]
Wu, B., Ji, M.-M., Zhao, X.-Y.	State-of-the-art of recycled mixed concrete (RMC) and composite structural members made of RMC.	2016	[44]
Wang, Y., Wang, Q., Geng, Y., Ranzi, G.	Long-term behaviour of simply supported composite slabs with recycled coarse aggregate.	2016	[45]
Lapko, A., Grygo, R.	Improving the structural behaviour RC precast concrete beams made of recycled aggregate concrete.	2016	[46]
Mohamad, N., Khalifa, H., Abdul Samad, A.A., Mendis, P., Goh, W.I.	Structural performance of recycled aggregate in CSP slab subjected to flexure load.	2016	[47]
Lopes Lima, P.R., Roque, A.B., Ariani Fontes, C.M., Feitosa Lima, J.M., Barros, J.A.O.	Potentialities of cement-based recycled materials reinforced with sisal fibers as a filler component of precast concrete slabs.	2017	[48]
Wang, Y.-Y., Wang, Q.-H., Geng, Y.	State-of-the-Art of Horizontal Structural Members Using Recycled Aggregate Concrete.	2018	[49]
Mikulica, K., Hela, R.	Usage of recycled concrete as subsoil under industrial floor.	2018	[50]
Lima, P.R.L., Barros, J.A.O., Roque, A.B., Fontes, C.M.A., Lima, J.M.F.	Short sisal fiber reinforced recycled concrete block for one-way precast concrete slabs.	2018	[51]
Chan, R., Santana, M.A., Oda, A.M., Paniguel, R.C., Vieira, L.B., Figueiredo, A.D., Galobardes, I.	Analysis of potential use of fibre reinforced recycled aggregate concrete for sustainable pavements.	2019	[52]
Deresa, S.T., Ren, H.T., Xu, J.J.	Flexural behavior of glubam-recycled aggregate concrete composite beam.	2020	[53]
Wang, Q., Yang, J., Liang, Y., Zhang, H., Zhao, Y., Ren, Q.	Prediction of time-dependent behaviour of steel-recycled aggregate concrete (RAC) composite slabs via thermo-mechanical finite element modelling.	2020	[54]
Zhang, H., Geng, Y., Wang, Y.-Y., Wang, Q.	Long-term behavior of continuous composite slabs made with 100 % fine and coarse recycled.	2020	[14]
Wang, Q.-H., Liang, Y.-Z., Zhang, H., Zhang, Y.-C., Ren, Q.-X.	Time-dependent behavior of multi-span continuous steel-RCA composite slabs considering the loading distribution effects.	2021	[55]
Tesfaye Deresa, S., Xu, J., Shan, B., Ren, H., Xiao, Y.	Experimental investigation on flexural behavior of full-scale glued laminated bamboo (glubam)-concrete composite beams: A case study of using recycled concrete aggregates.	2021	[56]
Awan, A.B., Shaikh, F.U.A.	Structural behavior of recycled tire crumb rubber sandwich panel in flexural bending.	2021	[57]
Zhang, H., Wang, Y.-Y., Wang, Q., Geng, Y.	Experimental study and prediction model for non-uniform shrinkage of recycled aggregate concrete in composite slabs.	2022	[58]
Yang, J., Liu, C., Wang, Q., Geng, Y.	Time-Dependent Behavior of Composite Steel-Recycled Aggregate Concrete Beams via Thermomechanical Finite Element Modeling.	2022	[59]
Zhang, H., Geng, Y., Wang, Y.-Y., Li, X.-Z.	Experimental study and prediction model for bond behaviour of steel-recycled aggregate concrete composite slabs.	2022	[18]
Zhao, H., Zhao, J., Wang, R., Zhang, W., Liu, F., Wu, S.	Thermal behavior of composite slabs with closed profiled steel decking and recycled aggregate concrete in fire.	2022	[60]
Zhang, H., Geng, Y., Wang, Q., Wang, Y.-Y.	Compounding effect between influences of fine and coarse recycled aggregates on non-uniform shrinkage behavior of steel-concrete composite slab section.	2022	[61]
Lu, L., Gao, M., Guo, Y., Wang, W., Yan, H., Jiang, T.	Experiments on flexural behavior of the prefabricated RAC and NWC composite slab.	2022	[62]
Zhang, H., Zhang, H.-Y., Geng, Y., Fang, P.-Q., Wang, Y.-Y.	Design formulae for Long-Term responses of continuous Steel-Recycled aggregate concrete composite slabs.	2022	[63]
Liu, E., Lin, M., Xie, Q., Zhang, Y.	Flexural Performance of Prestressed Composite Recycled Aggregate Slabs with Steel Tube Trusses.	2022	[64]
Lu, L., Wang, W., Zhang, L., Shao, Y.	Longitudinal shear strength of recycled aggregate concrete prefabricated superimposed slabs.	2023	[65]
Dong, J., Liu, Y., Yuan, S., Wang, Q., Wei, Z.	Study on fatigue performance of basalt fiber reinforced recycled concrete web box girder.	2023	[66]
Chen, B., Zhang, T., Geng, Y., Wang, Q., Zhao, G., Yang, J.	Longitudinal shear tests and design methods for corrugated steel-concrete composite slabs with recycled coarse aggregate.	2023	[67]
Zhang, R., Jiao, J., He, M., Tao, Z., He, P.	Design, implementation and performance prediction of profiled steel sheet-mixed aggregate recycled concrete hollow composite slab.	2023	[68]
Fareed, S., Khan, A.-U.-R.	Behavior of reinforced recycled aggregate concrete beams and slabs strengthened in flexure and punching with CFRP composites.	2024	[69]

(continued on next page)

Table 1 (continued)

Authors	Title	Year	Reference
Athulya, B., Jacob, M.M.	Numerical Investigation on Shear Bond Improvement of High Performance Concrete Composite Slabs Containing Recycled Aggregates.	2024	[70]
Niranjana, S., Jacob, M.M.	Numerical Analysis on Flexural Strength of Composite Slab with Inverted U-Shaped Shear Connector.	2024	[71]
Kefyalew, F., Imjai, T., Garcia, R., Khanh Son, N., Chaudhary, S.	Performance of recycled aggregate concrete composite metal decks under elevated temperatures: a comprehensive review.	2024	[72]
Stochino, F., Zucca, M., Simoncelli, M., Alibeigibeni, A., Concu, G., Valdes, M., Pisani, M.A., Bernuzzi, C., Saccone, M., Pani, L.	Experimental Investigation on the Structural Performance of Steel-Concrete Composite Slabs Incorporating Recycled Aggregates from Construction and Demolition Waste.	2024	[20]
Kefyalew, F., Imjai, T., Garcia, R., Kim, B.	Structural And Service Performance of Composite Slabs with High Recycled Aggregate Concrete Contents.	2024	[73]
Zhao, H., Wang, J., Zhao, J., Liu, F., Wang, R.	Fire performance of recycled aggregate concrete composite slabs with closed profiled steel decking.	2024	[74]
Elgaali, H.H., Lopez-Arias, M., Velay-Lizancos, M.	Accelerated CO ₂ exposure treatment to enhance bio-receptivity properties of mortars with natural and recycled concrete aggregate.	2024	[75]
Kefyalew, F., Imjai, T., Garcia, R., Son, N.K.	Fire behavior of high-contents recycled aggregate concrete composite slabs with small openings.	2024	[76]
Stochino, F., Alibeigibeni A, Zucca, M., Valdes, M., Concu, G., Simoncelli, M., Pisani, M.A., Bernuzzi, C.	Mechanical behavior of composite slabs with recycled concrete aggregates: A preliminary study.	2024	[77]

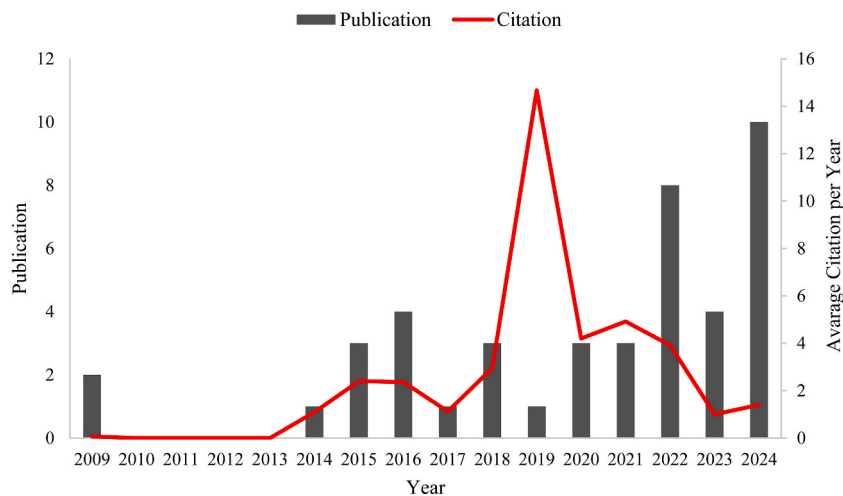


Fig. 2. Publication trend and average citation of Recycled Aggregate Concrete Composite Slab (RACCS).

articles to accurately assess the evolution of the field.

The Three-Field Plot in Fig. 3 offers a clear visualization of the relationships between cited sources (CR_SO), keywords (DE), and contributing countries (AU_CO) within the research on Recycled Aggregate Concrete Composite Slabs (RACCS). Each node is associated with a numerical value that indicates its connection strength within the dataset: for authors (CR_SO), the number represent the total number of link occurrences generated by their publications in combination with the keywords and countries; for keywords (DE), the value reflects the frequency of their co-occurrence with authors and countries; for countries (AU_CO), it indicates the total connections established with authors and keywords. This metric does not correspond simply to the number of publications but to the total weighted frequency of co-occurrences across the three selected fields. To improve clarity and comparability, the plot was limited to the top five authors, top six keywords, and top six contributing countries. In the case of keywords, the higher number of items was intentionally chosen to account for variations in term recognition (e.g., singular versus plural forms) and consequently detect the breadth of terminology used in the field. From the keywords (DE), it is evident that ("Recycled aggregate concrete"), ("Composite slabs"), and ("Recycled concrete") dominate the current research focus, emphasizing the importance of material properties and structural performance. The term ("Flexural behavior") emerges, highlighting a strong research focus on the flexural response of RACCS. However, it is significant to observe the absence of ("Longitudinal shear behavior") among the frequently used and correlated keywords, despite its critical role in ensuring the load transfer efficiency and overall structural integrity of composite slabs. This gap highlights an underexplored area of research that requires further attention. The cited sources show that authors like Zhang H., Xiao J., and Ranzi G. are key contributors, while the geographical contributions confirm China as the leading research hub, followed by emerging activity from Italy, Thailand, and other countries.

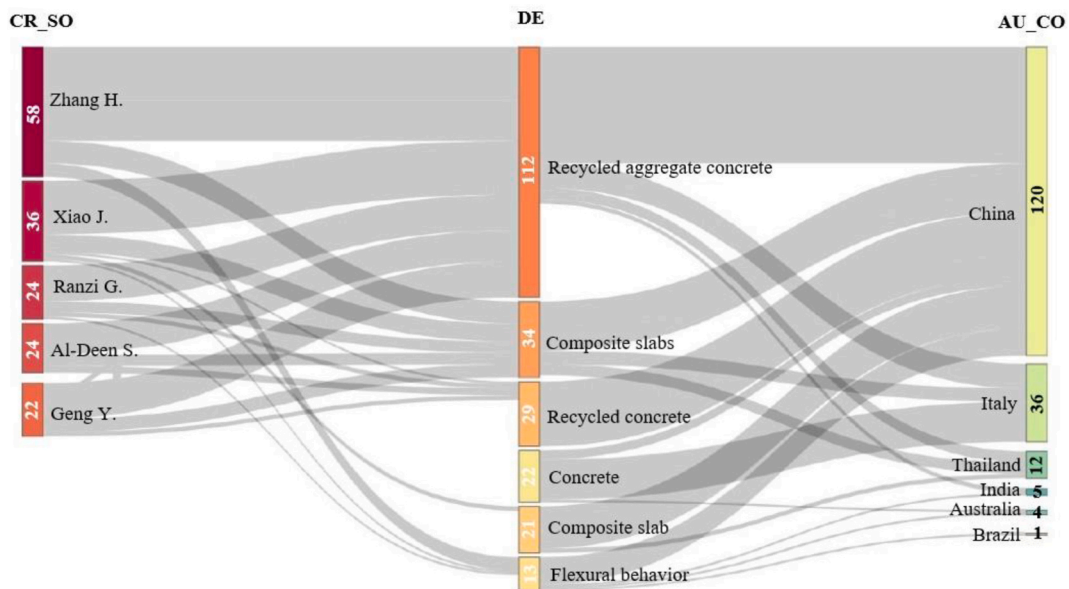


Fig. 3. Three-field plot of recycled aggregate concrete composite slab (RACCS).

This distribution suggests that a substantial portion of the available experimental evidence originates from Chinese research groups, a predominance that can be reasonably linked to the country's large population size and, consequently, a broader academic community active in the field, which naturally results in a higher research output and greater bibliometric density. To provide a more balanced view of contributions relative to population size, the plot was adjusted to include a broader range of countries, thus highlighting not only the leading hubs but also emerging research actors. Nonetheless, it is important to note that the methodologies used to assess longitudinal shear behaviour in composite slabs are well established and internationally recognized, leading to consistent evaluation approaches across different research contexts and avoiding major discrepancies in design standards worldwide. Overall, the Three-Field Plot highlights a strong thematic concentration on general RAC applications, with recurring keywords on composite slabs appearing in the literature but seldom explored in combination with recycled aggregates. This pattern underscores a fragmented and geographically uneven research landscape, where studies on composite slab systems and recycled aggregate concrete tend to evolve as separate lines of inquiry. As a result, coordinated and globally representative investigations addressing their combined effect, particularly on the longitudinal shear response of composite slabs, remain scarce, leaving this area underdeveloped despite its relevance for design and structural safety.

The text-mining cluster network analysis of Recycled Aggregate Concrete Composite Slabs (RACCS) in Fig. 4, performed by *SciMat* [37,78], highlights the progression of research from 2013 to 2024, reflecting both the evolution of themes and emerging gaps in the field. The analysis was deliberately started in 2013, as highlighted by the publication trend in Fig. 2, which shows that no relevant studies on RACCS were present in the dataset between 2009 and 2013. This temporal adjustment ensured a consistent and meaningful mapping of thematic developments, avoiding empty periods that could bias the visualization of research clusters and their evolution over time. The cluster mapping analysis was carried out using *SciMAT*'s default co-word clustering algorithms and the simple centers strategy for theme detection. The co-occurrence matrix was normalized using the equivalence index, as recommended for conceptual structure mapping, and the minimum frequency threshold was set to one document per keyword, allowing emerging themes (e.g., CDW, longitudinal shear) to be captured rather than excluded due to low occurrence.

During 2013–2017, research activity within the dataset was primarily concentrated on the cluster labelled Composite Slabs, which accounted for 4 core documents. This cluster recorded a centrality score of 65.6, indicating a moderate degree of connectivity to other thematic areas within the network, and a density score of 33.3, suggesting that the internal cohesion of studies within this theme was relatively limited, with contributions not yet forming a highly interconnected body of knowledge. Strong links were observed with structural performance concepts such as Flexural Behaviour (3 documents) and Failure Mechanics (2 documents), which were frequently co-addressed with composite slab studies to investigate load-bearing mechanisms and failure modes. Ductility, despite being represented by a single document, showed a relatively thicker connection line, indicating that it was more tightly correlated with multiple other themes within the network, particularly with Flexural Behaviour and Composite Slab, pointing to its perceived relevance in structural performance evaluations. In contrast, Construction and Demolition Waste (CDW) appeared as a marginal node with only 1 document, and the small size of the node and the absence of direct connections indicate a lack of exploration of its impact on mechanical properties, despite its initial recognition as a potentially sustainable material. These bibliometric patterns highlight that research in this early stage mainly addressed conventional mechanical aspects of composite slabs, while sustainability-oriented approaches and the use of recycled aggregates remained largely peripheral and insufficiently integrated into the thematic core of the field.

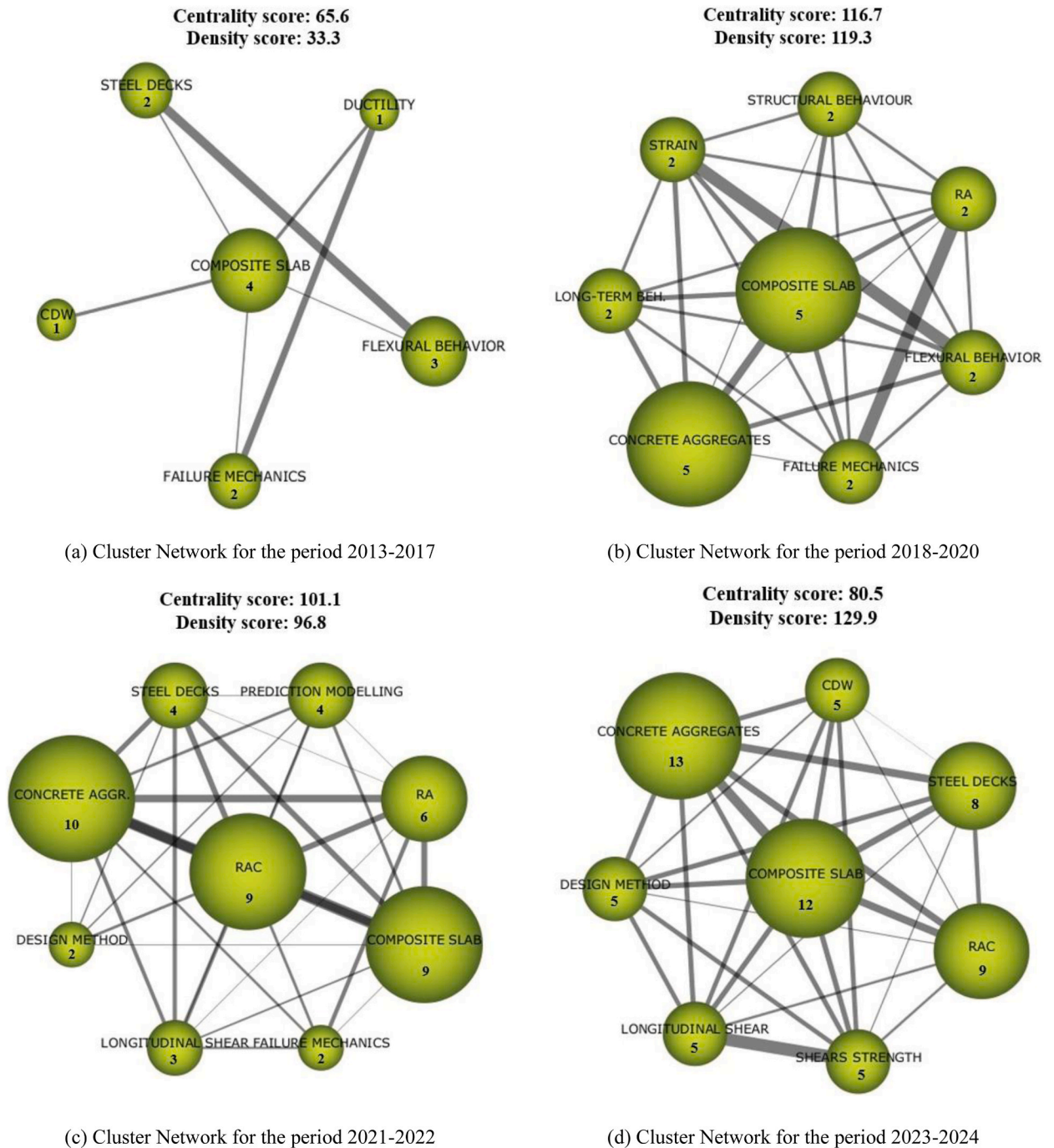


Fig. 4. Cluster Network Analysis (2013–2024): Evolution of the key themes in Recycled Aggregate Concrete Composite Slabs (RACCS), highlighting shifts from structural properties to sustainability and emerging topics like longitudinal shear performance.

Between 2018 and 2020, the focus shifted toward greater emphasis on sustainability, with Recycled Aggregates (RA) gaining prominence. The cluster Composite Slab maintained a dominant role in the thematic network, supported by 5 core documents, a centrality score of 116.7, and a density value of 119.3. The high centrality score reflects the strong capability of this theme to act as a bridge, connecting different research topics such as Recycled Aggregate (RA), Concrete Aggregates, Flexural Behaviour, and Failure Mechanism. At the same time, the relatively high-density value indicates a well-developed and cohesive internal structure within the cluster, meaning that the selected studies show strong interconnections and recurring co-occurrences of keywords related to composite slabs. Despite this high relevance and integration within the research network, the absolute number of documents remains low, with

only two studies directly linking RA to composite slab behaviour. This reveals that sustainability considerations were still in their early stages of incorporation into composite slab research, and detailed analyses of longitudinal shear performance in RACCS had not yet been systematically explored. Emerging connections with Strain, Structural Behaviour, and Long-Term Behaviour suggest growing interest in the mechanical response and durability aspects of these systems, but a consolidated and coordinated research effort was still lacking during this period.

During 2021–2022, research on RACCS exhibited stronger thematic interconnections compared to previous periods, with the cluster RAC achieving a centrality score of 101.12 and a density score of 96.79, indicating both high relevance within the network and a well-developed internal structure. This period shows notable progress in linking Composite Slabs (9 documents), Concrete Aggregates (10 documents), and Longitudinal Shear (2 documents), reflecting an emerging interest in directly assessing longitudinal shear transfer mechanisms in RACCS. The appearance of Design Methods and Prediction Modelling within the network demonstrates increasing efforts to move from conceptual discussions toward practical frameworks for design and performance optimization. However, the relatively small size of the Design Methods node, combined with its limited connections compared to RAC and Composite Slabs, indicates that further research is needed to consolidate advanced design strategies specifically targeting longitudinal shear behaviour in RACCS systems. While the thematic network suggests an initial attempt to integrate design approaches with sustainability-driven material innovations, the body of evidence remains limited, leaving significant room for deeper methodological development and broader experimental validation.

During 2023–2024, research on RACCS exhibited a marked consolidation of thematic interconnections, with the Composite Slabs cluster re-emerging as the dominant focal point. This cluster achieved a centrality score of 80.5 and a density value of 129.9, supported by 12 associated documents, highlighting its strong relevance and internal cohesiveness within the research network. Enhanced links were observed between RAC (9 documents), Shear Strength (5 documents), Longitudinal Shear (5 documents), and Concrete Aggregates (13 documents), demonstrating significant progress in associating recycled materials with key structural performance parameters. The cluster network highlights improved integration between sustainability-oriented materials and structural aspects, showing that research is increasingly addressing the mechanical behaviour of RACCS in a more comprehensive way. Notably, a connection was established between Design Methods (5 documents) and Longitudinal Shear, suggesting a growing attempt to translate theoretical findings into practical design recommendations. However, the relatively small node size and limited connection thickness of Design Methods compared to the central Composite Slabs and Concrete Aggregates nodes indicate that, while this topic is emerging, further investigation is required to fully incorporate advanced design strategies into the optimization of longitudinal shear performance in RACCS systems. Additionally, the inclusion of Construction and Demolition Waste (CDW) and Steel Decks among the linked nodes shows a broader focus on sustainability and composite action components, yet the strength of their links remains lower, signaling room for deeper exploration of their combined influence on longitudinal shear transfer mechanisms.

The landscape depicted in Fig. 4, characterized by an increasingly dense network of correlations, reflects a progressive consolidation of knowledge on composite slab systems, with a growing emphasis on sustainability, RAC, and their structural performance. Despite this positive evolution, the analysis reveals a persistent gap: research efforts addressing design methods specifically tailored to optimize the longitudinal shear behaviour of RACCS remain scarce and fragmented. While fundamental evaluation approaches are well established and internationally recognized, their targeted adaptation to RACCS applications is still limited. Bridging this gap requires a deeper, methodologically structured investigation of available design strategies, enabling the development of optimized, reliable, and globally transferable solutions for enhancing longitudinal shear performance in RACCS.

4. Longitudinal shear bond behaviour and failure mechanisms in composite slabs

The behaviour and strength of composite slabs are primarily influenced by the longitudinal shear bond at the interface between the profiled steel sheeting and the concrete. The bond mechanism at the steel–concrete interface primarily relies on mechanical interlocking in combination with frictional resistance [79]. Its effectiveness is governed by several parameters, such as the geometry of the profiled sheeting (type, size, thickness, rib spacing, embossment depth, and orientation), surface roughness, and the mechanical properties of both steel and concrete [80]. Numerous researchers have investigated different parameters to assess the bond strength of composite slabs. For instance, Wright H. et al. [81] noted that changes in concrete strength and cyclic loading have a minimal effect on slab capacity, while embossment height plays a significant role in ultimate strength. Mäkeläinen P. et al. [82] explored the longitudinal shear behaviour by altering the profiled steel sheeting's shape, size, and thickness, emphasizing that embossment depth has a more substantial impact than its length and shape. Burnet M. J. et al. [83] conducted thirty-three tests to identify the key factors affecting the chemical and mechanical bond strength of shear connectors. Their findings indicate that geometry, embossments, and surface preparation are critical for bond effectiveness. Given the complexity of the involved factors, establishing universal design values for all slab conditions is difficult. The longitudinal shear strength is typically assessed through full-scale bending tests, where the bond-slip relationship is analyzed. The maximum longitudinal shear stress is calculated using two distinct methods prescribed by Eurocode 4 [27]: the *m-k* method and the *Partial Shear Connection Method* (PSM). Fig. 5 shows a typical composite slab specimen subjected to a four-point bending test and its corresponding cross-section. Composite slabs can exhibit three main failure modes.

- (i) Vertical shear failure at section (*a-a*)
- (ii) Flexural failure at the peak moment region at section (*b-b*)
- (iii) Longitudinal shear failure at section (*c-c*)

Longitudinal shear failure refers to the progressive loss of interfacial bond, resulting in horizontal relative slip between the two

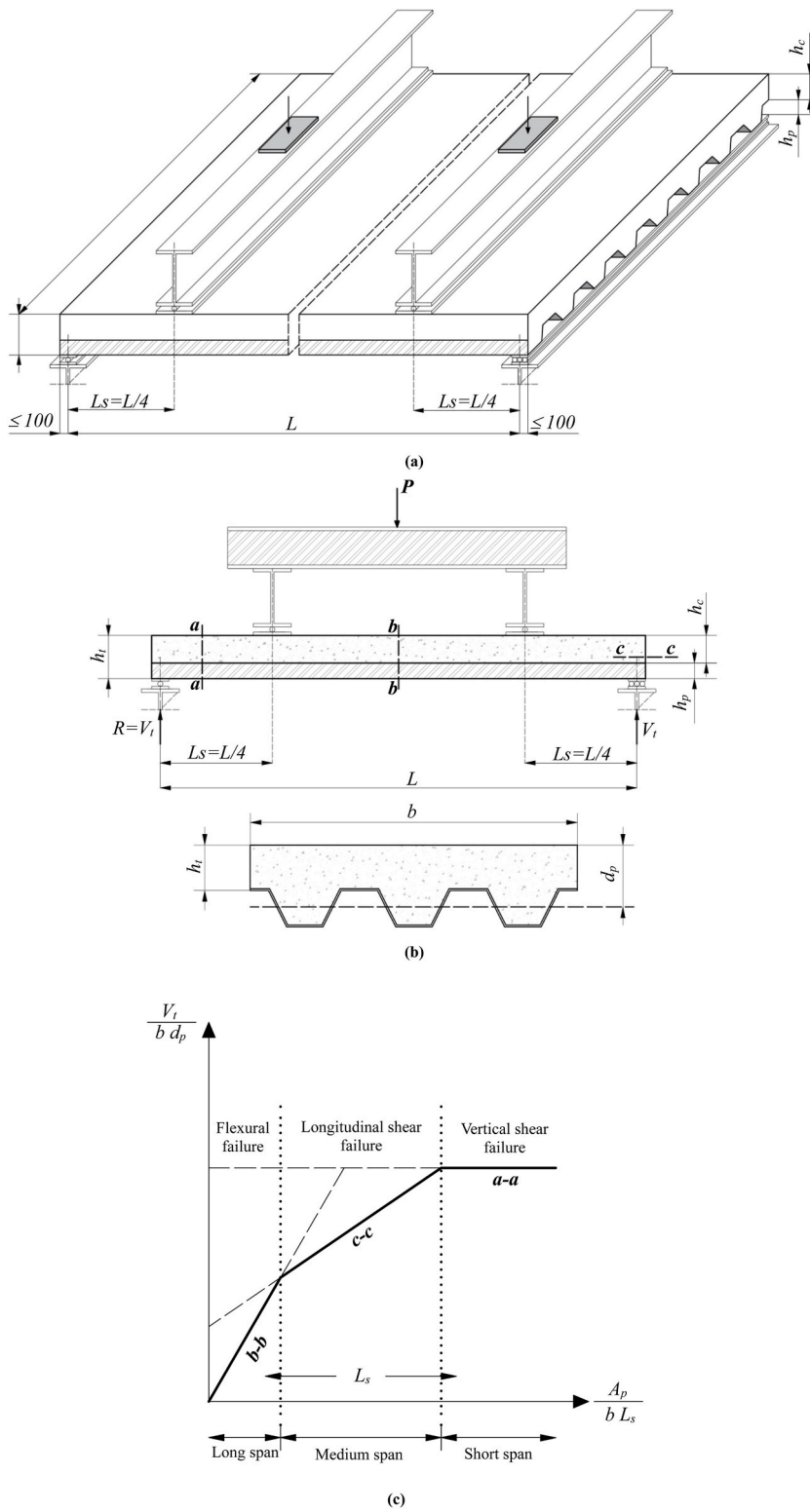


Fig. 5. (a) Full-scale test: four-point bending test, (b) Elevation and cross-section of a slab specimen in a four-point bending test, (c) Shear stress versus inverted slenderness in a four-point bending test.

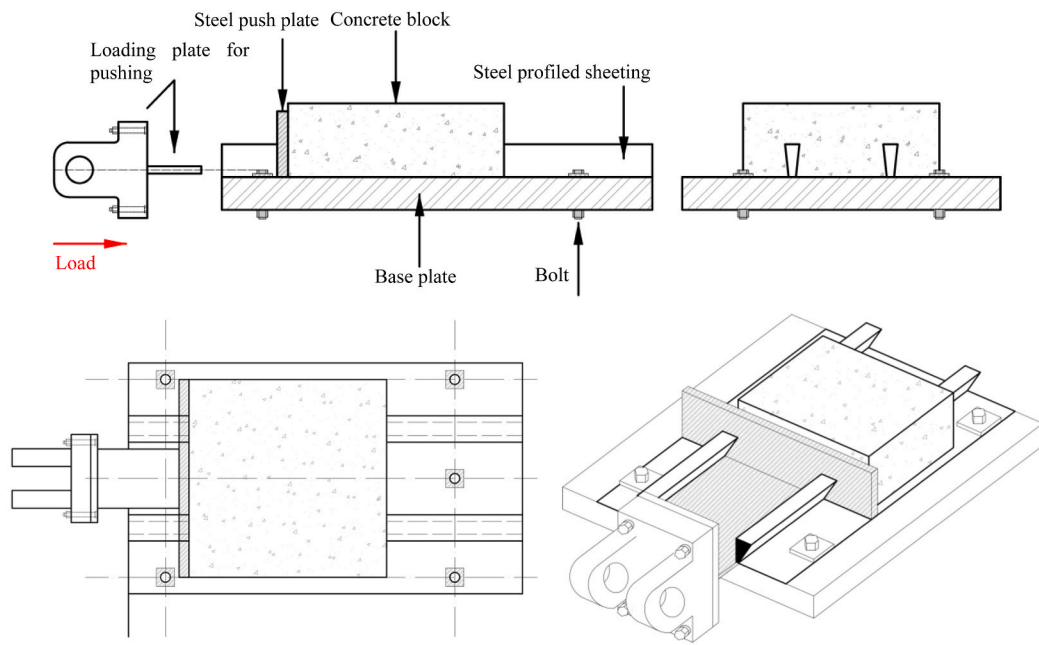


Fig. 6. Side, front, plan, and 3D-view of the push-off test.

materials under increasing flexural load, often occurring well before the slab reaches its ultimate bending capacity [84]. It is a highly nonlinear phenomenon governed by the complex interfacial behaviour between the profiled steel sheeting and the concrete, resulting in a marked reduction in both stiffness and load-bearing capacity [80]. Due to its significant impact on structural performance, longitudinal shear failure is considered one of the most critical failure mechanisms to address in composite slab design practice. Fig. 5

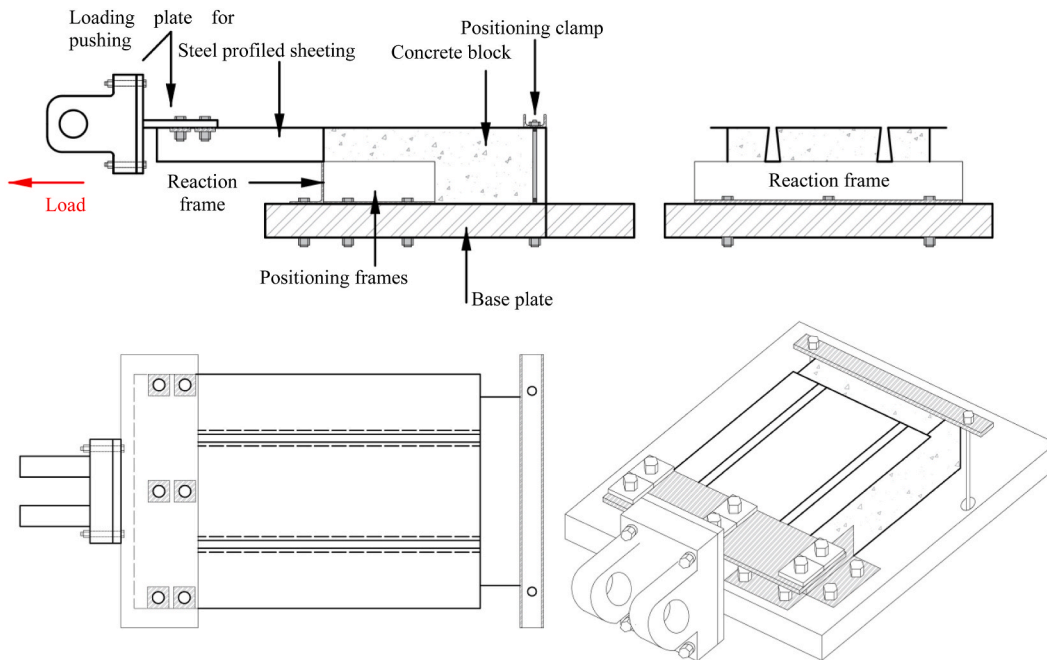


Fig. 7. Side, front, plan, and 3D-view of the pull-off test.

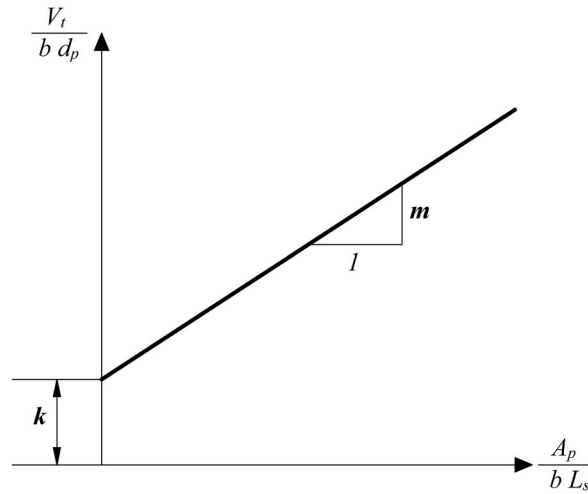


Fig. 8. Linear regression analysis plot of *m-k* method.

(c) presents the relationship between the nominal shear stress ($V_t/b \cdot d_p$) and the inverse slenderness of the slab ($A_p/b \cdot L_s$), where V_t represents the support reaction, A_p is the cross-section area of the profiled steel decking, b is the width of the slab cross-section, d_p is the effective depth of the slab, and L_s is the shear span. By varying the shear span (L_s), each of the previously described failure modes aligns with distinct regions on the graph. The most common failure mode in medium-span slabs is associated with longitudinal shear collapse, characterized by slip occurring between the profiled steel sheeting and the concrete under relatively high load levels, resulting in substantially reduced stiffness and strength [85].

The high cost and complexity of the experimental investigations recommended by Eurocode 4 [27] prompted researchers to develop simpler, small-scale tests. An alternative approach involves modelling the longitudinal shear bond through tests conducted on smaller samples. Crisinel M. et al. [86] introduced a new simplified method to predict the behaviour of composite slabs, considering

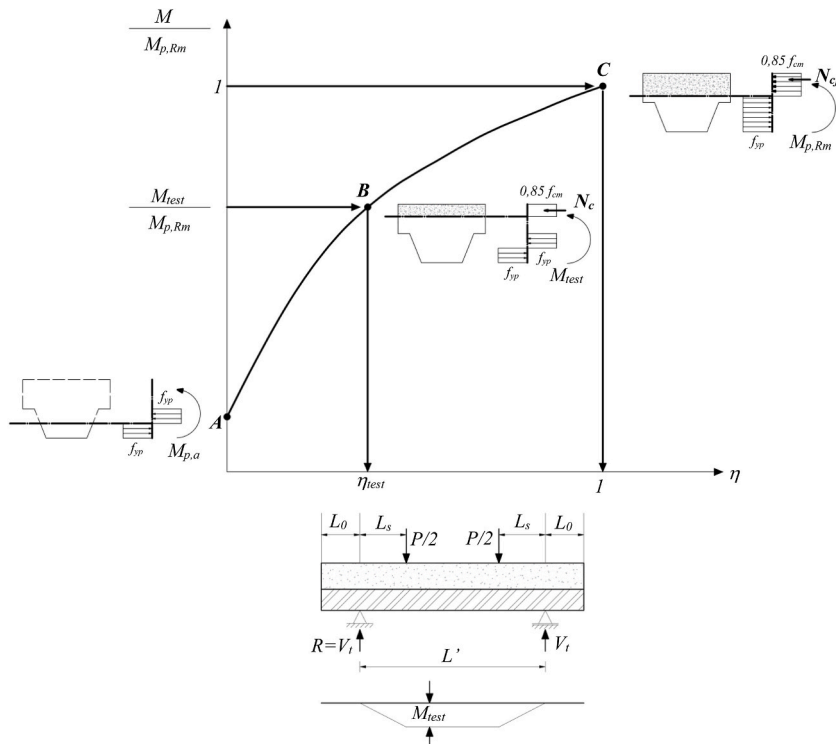


Fig. 9. Degree of shear connection determined from M_{test} .

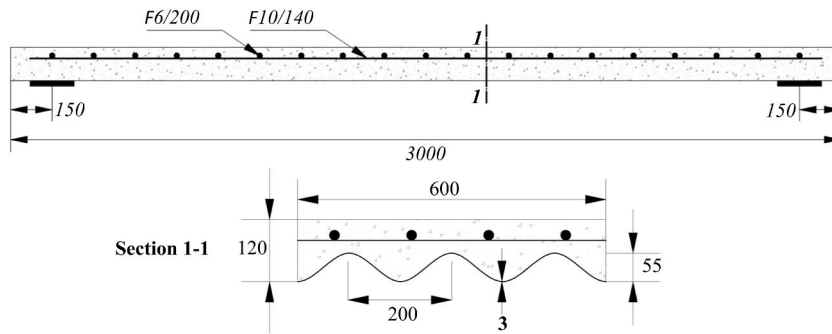


Fig. 10. Schematic diagram of the specimen (dimensions in mm).

the material properties of both steel and concrete, as well as the slab dimensions, to determine the shear bond characteristics at the steel-concrete interface from small-scale pull-out tests. Burnet M.J. et al. [83] reviewed existing pull-out test methods developed by other researchers and subsequently introduced a new approach based on concrete pushing, referred to as the push-off test.

Accurately modelling the interaction between the steel deck and concrete, represented by longitudinal shear stress, is crucial for making reliable predictions. This interaction is governed by the bond-slip behaviour, which describes the non-linear relationship between interfacial shear stress (τ) and relative slip (s) developing along the interface. Under increasing horizontal shear force, partial degradation of chemical adhesion and mechanical interlock may occur, leading to progressive slip localization, a reduction in stiffness, and redistribution of shear stress. When the shear transfer capacity becomes insufficient, the frictional mechanism ultimately governs the onset of longitudinal shear failure [86]. To investigate this phenomenon, small-scale push-off and pull-out tests are commonly employed [87]. These tests are specifically designed to reproduce the interface conditions under longitudinal shear and enable the experimental derivation of the τ - s curve, which characterizes the interfacial shear response of composite slabs. Fig. 6 shows the configuration of the experimental setup for the push-off test on a composite slab sample, highlighting both the side, front, and plan views for a clear understanding of the setup. Similarly, Fig. 7 illustrates the pull-out test setup.

In a composite slab incorporating RCA, longitudinal shear failure is strongly influenced by the altered interfacial properties of RCA. Due to the higher porosity and weaker interfacial transition zones (ITZs) associated with recycled aggregates, the mechanical interlock with the steel deck is often less effective, leading to premature micro-shear cracking around the embossments. This early damage reduces the initial shear transfer capacity and triggers the onset of longitudinal slip at lower load levels. However, the rougher and more irregular surface texture of recycled aggregates could enhance frictional resistance in the post-peak stage, partially compensating for the loss of mechanical interlock. This results in an earlier onset of the longitudinal shear failure mechanism, manifested by progressive horizontal slip and partial detachment between steel and concrete under increasing flexural loading [4,88]. The reduced interlock capacity, combined with the consequent modification of the frictional response, alters the typical bond-slip behaviour of RCA-based slabs compared to conventional concrete, representing a technical bottleneck for accurately predicting longitudinal shear resistance using current design formulations, which are further discussed in Section 5.

5. Current theoretical debonding models

As described in Eurocode 4 [27], current design approaches for steel-concrete composite slabs offer two primary methods for evaluating the longitudinal shear capacity: the m - k method and the *Partial Shear Connection Method* (PSM). Both methods rely heavily on experimental data obtained from full-scale bending tests. However, they differ in their approach: the PSM is based on a partial

Table 2

Specimen parameters and numbers [65]. Notes: L_e is the effective span of the superimposed deck slabs, L_s is the shear span length, t_s is the profiled steel sheeting thickness, h is the total height of the slab, r_{RCA} is the recycled concrete aggregate replacement ratio.

Group number	Specimen number	L_e (mm)	L_s (mm)	t_s (mm)	h (mm)	r_{RCA} (%)
RAC-0	RAC-0-700-1	2800	700	1.0	150	0
	RAC-0-700-2	2800	700	1.0	150	0
	RAC-0-770-1	2800	770	1.0	150	0
	RAC-0-770-2	2800	770	1.0	150	0
	RAC0-840-1	2800	840	1.0	150	0
	RAC0-840-2	2800	840	1.0	150	0
RAC-50	RAC-50-700-1	2800	700	1.0	150	50
	RAC-50-700-2	2800	700	1.0	150	50
	RAC-50-770-1	2800	770	1.0	150	50
	RAC-50-770-2	2800	770	1.0	150	50
	RAC-50-840-1	2800	840	1.0	150	50
	RAC-50-840-2	2800	840	1.0	150	50

connection model derived from composite beam theory, while the *m-k* method employs a statistical procedure for interpolating and extrapolating experimental data. The *m-k* method, primarily developed from the work of Porter and Ekberg [28,89], assesses the longitudinal shear design resistance V_{Ed} by ensuring that the maximum design shear does not exceed the calculated longitudinal shear resistance $V_{L,Rd}$ as shown in the following Eq. (1):

$$V_{L,Rd} = \frac{b d_p}{\gamma_s} \left(m \frac{A_p}{b L_s} + k \right) \tag{1}$$

where b is the width of the slab in mm, d_p is the distance in mm between the centreline of the profiled steel sheeting and the outer part of the composite slab under compression as shown in Fig. 5 (b), A_p is the effective area in mm² of the cross-section of the steel sheet, L_s represents the shear span, γ_s is the partial safety factor for the ultimate limit state with a recommended value of $\gamma_s = 1.25$, and *m-k* are the experimentally determined coefficients through a four-point bending test in N/mm². The experimental setup for the test is illustrated in Fig. 5 (a). The method involves rewriting Eq. (1) in the form of Eq. (2), where *X* and *Y* represent the independent and dependent variables, respectively, and performing a linear regression analysis to obtain the plot shown in Fig. 8, which relates the

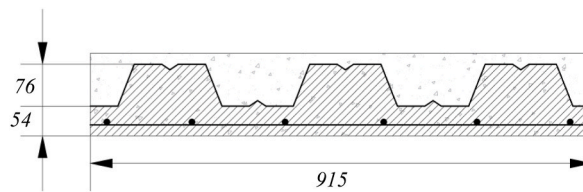


Fig. 11. Section of the superimposed slab (dimension in mm).

Table 3

Details for the pull-out test specimens [18]. Notes: *W* stands for the width of slabs, h_r is the rib height, t_s is the steel deck thickness, *w/c* is the water-to-cement ratio, and r_{RCA} is the recycled concrete aggregate replacement ratio.

Specimens	Dimensions (mm)			h_r (mm)	t_s (mm)	<i>w/c</i>	r_{RCA} (%)
	l	b	W				
CS65-1.2-0.31-0 %	300	510	120	65	1.2	0.31	0
CS65-1.2-0.31-100 %	300	510	120	65	1.2	0.31	100
CS65-1.2-0.45-0 %	300	510	120	65	1.2	0.45	0
CS65-1.2-0.45-50 %	300	510	120	65	1.2	0.45	50
CS65-1.2-0.45-100 %	300	510	120	65	1.2	0.45	100
CS65-1.2-0.60-0 %	300	510	120	65	1.2	0.60	0
CS65-1.2-0.60-100 %	300	510	120	65	1.2	0.60	100
CS65-1.0-0.45-0 %	300	510	120	65	1.0	0.45	0
CS65-1.0-0.45-50 %	300	510	120	65	1.0	0.45	50
CS65-1.0-0.45-100 %	300	510	120	65	1.0	0.45	100
CS65-0.8-0.45-0 %	300	510	120	65	0.8	0.45	0
CS65-0.8-0.45-50 %	300	510	120	65	0.8	0.45	50
CS65-0.8-0.45-100 %	300	510	120	65	0.8	0.45	100
CS48-0.8-0.45-0 %	300	600	120	48	0.8	0.45	0
CS48-0.8-0.45-100 %	300	600	120	48	0.8	0.45	100

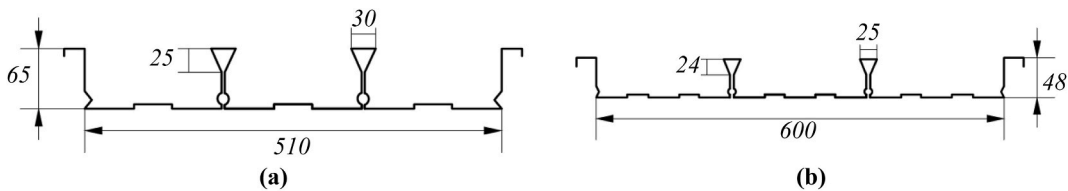


Fig. 12. Details of the profiled steel decks (dimensions in mm).

Table 4

Basic characteristics of aggregates [67].

Aggregate	Apparent density (kg/m ³)	Water absorption (%)	Water content (%)
NCA	2681	0.75	0.26
RCA	2597	3.75	2.60
NFA	2625	—	3.60

nominal shear stress to the inverse slenderness of the slab.

$$Y = m X + k \quad (2)$$

From this plot, the parameters m and k are derived, where m represents the slope of the regression line and k represents its y -intercept.

Although experimental evidence does not always confirm this behaviour [90], the *Partial Shear Connection Method* (PSM), determines the flexural capacity of the composite slab through a straightforward plastic analysis of the cross-section, considering both the concrete and the profiled steel sheeting, as shown in Fig. 9. Based on longitudinal shear tests, the bending moment at mid-span of the slab is denoted as M_{test} , and the degree of shear connection η_{test} is defined as Eq. (3), where N_c represents the compression force in the concrete, and N_{cf} is the compression force in the concrete at full shear connection. From the formulation of the degree of shear connection in Eq. (3), it is possible to express the value of N_c as shown in Eq. (4).

$$\eta_{test} = \frac{N_c}{N_{cf}} \quad (3)$$

$$N_c = \eta N_{cf} \quad (4)$$

At full shear connection, the flexural resistance of the section, denoted as $M_{p,Rm}$, can be represented by Eq. (5) for a unit degree of shear connection, η . In this context, z refers to the internal moment arm, while $M_{p,r}$ denotes the reduced plastic moment resistance of the profiled steel sheeting. This reduction accounts for the effect of axial tensile forces, as expressed in Eq. (6), where $M_{p,a}$ is the design value of the plastic resistance moment for the effective cross-section of the profiled steel sheeting.

$$M_{p,Rm} = \eta N_{cf} \cdot z + M_{p,r} \quad (5)$$

$$M_{p,r} = 1,25 M_{p,a} \left(1 - \frac{\eta N_{cf}}{N_{p,a}} \right) \leq M_{p,a} \quad (6)$$

Based on the previous analysis, the mean value for the ultimate longitudinal shear stress τ_u can be determined using Eq. (7) [27].

$$\tau_u = \frac{\eta_{test} N_{cf}}{b(L_s + L_0)} \quad (7)$$

Table 5

Concrete mix proportions and basic mechanical properties [67]. Notes: r_{RCA} is the recycled concrete aggregate replacement ratio; w/c is the water-to-cement ratio; c is the cement; w_a is the effective water consumption; w_e is the extra water consumption; AE is the water-reducing agent.

Specimen ID	r_{RCA} (%)	w/c	Concrete mix proportions (kg/m ³)							Slump (mm)	Basic mechanical properties	
			c	w_a	w_e	NFA	NCA	RCA	AE		f_c (MPa)	E_c (MPa)
CSRAC-0	0	0.45	400	167	0	670	1191	0	4	140	62.04	38.66
CSRAC-50	50				6		595	576		160	52.04	32.77
CSRAC-100	100				13		0	1154		170	46.25	29.43

Table 6

Mechanical properties of steel [67].

Steel	Yield strength f_y (MPa)	Ultimate tensile strength f_u (MPa)	Elastic modulus E_s (GPa)
Corrugated steel plate	397.4	497.2	210
Reinforcement	242.3	370.6	205
Studs	320.0	400.0	210

Table 7

The mixture ratio and compressive mechanical properties of RAC [65]. Notes: r_{RCA} is the natural coarse aggregate replacement ratio.

Material	Cement (kg)	Sand (kg)	Stone (kg)	RCA (kg)	Water (kg)	Water reducer (kg)	Cubic compressive strength (MPa)	Elasticity modulus (GPa)	r_{RCA} (%)
RAC-0	360	727	1138	0	175	1.8	38.8	32.5	0
RAC-30	377	695	797	303	177	1.8	44.0	37.5	30
RAC-40	389	672	683	405	179	1.8	41.0	35.0	40
RAC-50	398	646	574	489	180	1.8	41.7	35.0	50
RAC-60	414	630	455	607	182	1.8	47.5	36.5	60
RAC-70	426	619	341	708	183	1.8	41.6	35.0	70

The Force Equilibrium method represents a new approach for modeling the longitudinal shear bond in composite slabs [91,92]. This method, which is not yet recognized by Eurocode 4 [27], is based on the slab slenderness—defined as the ratio of the shear span length to the effective depth of the concrete—and on experimental data obtained from small-scale bending tests on composite slab specimens made using trapezoidal sheeting. The maximum shear stress value obtained using this method can be applied to other analytical approaches, such as the PSM method for slab design [91]. The aforementioned methods for evaluating longitudinal shear behaviour have been specifically designed and developed for conventional concrete-steel composite slabs utilizing Natural Concrete Aggregates (NCA).

6. Literature review of design method for longitudinal shear behaviour in RACCS

Research on the longitudinal shear behaviour of composite slabs, particularly those utilizing Recycled Concrete Aggregate (RCA), remains fragmented and significantly underrepresented in the scientific literature, despite the growing interest in sustainable alternatives to natural aggregate. While numerous investigations have explored the mechanical properties of RCA and its use in conventional reinforced concrete elements, only a limited number of studies have addressed its application in composite slabs, and more specifically, its influence on longitudinal shear mechanism at the steel-concrete interface, which governs composite action and it is critical for structural safety and serviceability. The systematic literature review presented in Section 3 revealed that most experimental studies on RACCS have focused primarily on global flexural behaviour or ultimate load-bearing capacity, offering only limited understanding of the fundamental interface mechanisms that govern the design of longitudinal shear resistance. Key parameters such as the bond-slip relationship (τ - s curve), the contribution of mechanical interlock and frictional mechanisms, and their sensitivity to variations in aggregate quality or replacement ratio have been explicitly investigated in only three experimental studies, while most of the available research does not directly assess these critical aspects of longitudinal shear behaviour. Given these limitations, the scope of this review was deliberately narrowed to focus on three pivotal case studies, identified as the only experimental investigations that analyze critical aspects of longitudinal shear performance in Recycled Aggregate Concrete Composite Slab (RACCS). These works try to evaluate whether the existing approaches used for natural aggregate concrete (e.g., empirical formulations and design rules in Eurocode 4) remain valid for RAC applications or require modification. The selected studies are unique in proposing calibrated parameters or discussing the effectiveness of current code-based methods, making them directly relevant for future standardization efforts and safe implementation of RACCS.

Each study is presented with a focus on its objectives, methodologies, and findings, exploring.

Table 8

Material properties of profiled steel sheeting and reinforcements [65]. Notes: t_s is the thickness of profiled steel sheeting; d is the reinforcement diameter; f_y is the yield strength; f_u is the ultimate tensile strength; E_s is the elastic modulus.

t_s or d (mm)	f_y (MPa)	f_u (MPa)	E_s (10^5 MPa)	Elongation δ (%)
1.0	226.36	339.47	1.975	42
6.0	383	453	1.77	33
8.0	445	660	2.01	27

Table 9

RCA and NCA mix proportions [18]. Notes: r_{RCA} is the recycled concrete aggregate replacement ratio, *SP* is short for superplasticizer.

w/c	r_{RCA} (%)	Mass content of materials (kg/m^3)					
		Water	Cement	NCA	RCA	Sand	SP
0.31	0	180	581	1085	0	611	2.9
0.31	100	180	581	0	1083	611	2.9
0.45	0	180	400	1185	0	667	2.0
0.45	50	180	400	592	591	667	2.0
0.45	100	180	400	0	1182	667	2.0
0.60	0	180	300	1240	0	698	1.5
0.60	100	180	300	0	1237	698	1.5

Table 10

Mechanical properties of profiled steel decks [18].

Type of steel decks	t_s (mm)	E_s (GPa)	μ_s	f_y (MPa)
DW65	0.8	195	0.276	284
	1.0	176	0.283	340
	1.2	206	0.279	341
DW48	0.8	198	0.291	300
	1.2	186	0.293	290

- i. The role of recycled aggregate replacement ratio in influencing longitudinal shear behaviour;
- ii. The analysis of load-deflection and load-slip curves derived from experimental investigation;
- iii. The development of innovative design methodologies, supported by experimental analysis, to optimize longitudinal shear performance.

6.1. Aim of the studies

The first study, conducted by Chen B. et al. [67], evaluates the impact of recycled concrete aggregate replacement ratio (r_{RCA}) and the configuration of end anchorage on the longitudinal shear performance of Corrugated Steel-Recycled Aggregate Concrete (CSRAC) composite slabs. Six specimens were tested to analyze their failure modes, load-bearing capacity, and deformation behaviour. The schematic diagram of the specimens is illustrated in Fig. 10. The four-point bending test was conducted following the provisions of Eurocode 4 [27] for steel-concrete composite structures.

In the second reference case study, Lu L. et al. [65] conducted twelve full-scale bending tests on superimposed slabs, varying both the shear span and the replacement ratio of recycled coarse aggregate concrete (r_{RCA}). The slabs were divided into two groups based on the aggregate replacement ratio, as outlined in Table 2, while the schematic configuration of the specimens is illustrated in Fig. 11.

The experimental study investigated the behaviour of superimposed slab specimens under static monotonic loading using symmetrical double-line loads. The schematic setup and test arrangement are illustrated in Fig. 5. Subsequently, the factors influencing the flexural and longitudinal shear behaviour of the slabs were examined through sixty-six finite element models (FEM). Based on the experimental findings and the m - k method, as detailed in Section 5, a simplified calculation method was proposed for designing longitudinal shear resistance.

Table 11
Mechanical properties of aggregates [18].

Properties	NCA	RCA	Sand
Oven-dried Density (kg/m^3)	2801	2660	2597
SSD density (kg/m^3)	2821	2796	–
Water absorption ratio (%)	0.7	5.1	1.11
Residual mortar content (%)	–	40	–

Table 12
Mechanical properties of NAC and RAC [18].

w/c	r_{RCA} (%)	f_c (MPa)	f_t (MPa)	E_c (GPa)
0.31	0	70.2	4.31	39.2
0.31	100	63.4	3.60	33.1
0.45	0	55.6	3.74	34.4
0.45	50	51.4	3.14	32.3
0.45	100	50.0	2.90	30.5
0.60	0	46.5	2.44	32.5
0.60	100	39.5	2.14	30.8

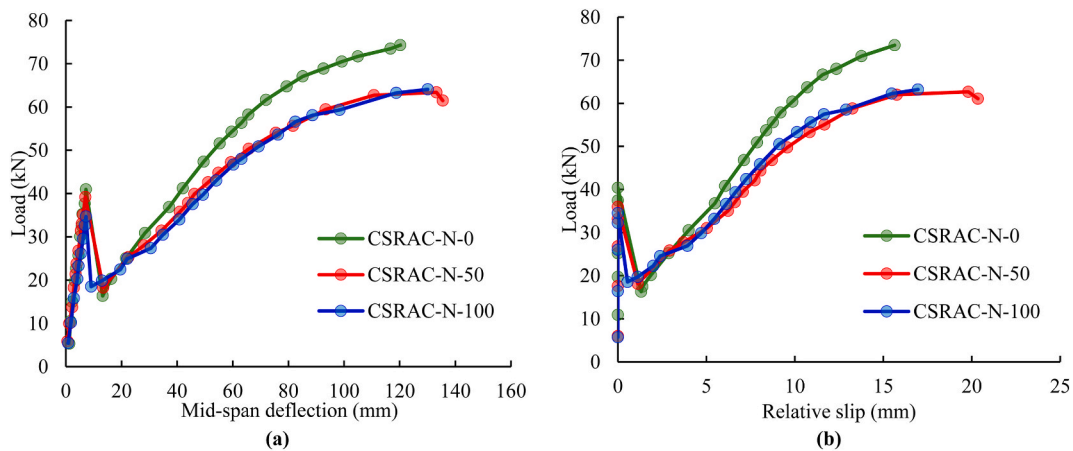


Fig. 13. Load-deformation curves of CSRAC composite slabs without end anchorages: (a) Load-midspan deflection curve, (b) Load-slip curve [67]. The sample is identified by the label Corrugate Steel Recycled Aggregate Concrete (CSRAC) composite slab without end anchorages (N).

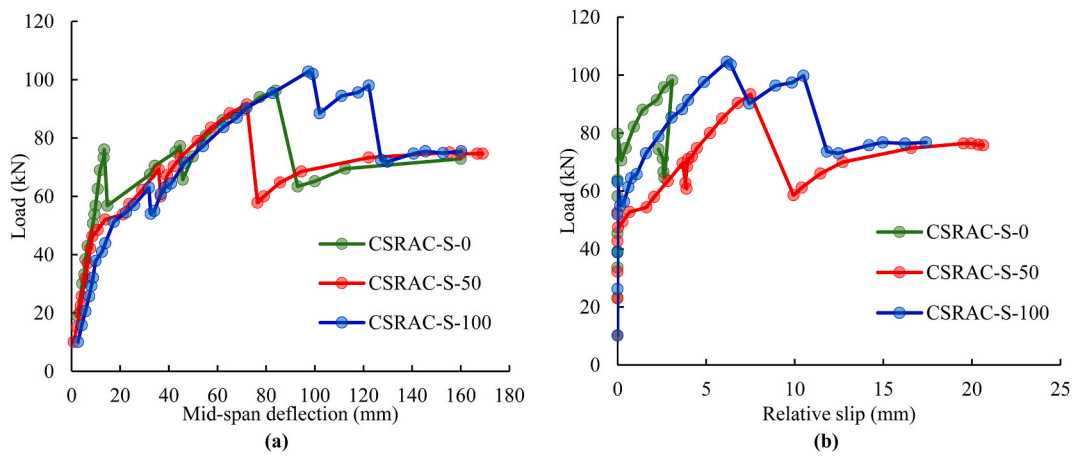


Fig. 14. Load-deformation curves of CSRAC composite slabs with end anchorages: (a) Load-midspan deflection curve, (b) Load-slip curve [67]. The sample is identified by the label Corrugate Steel Recycled Aggregate Concrete (CSRAC) composite slab with end anchorages (S).

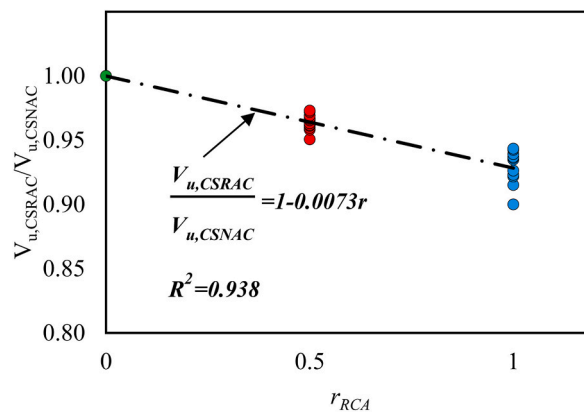


Fig. 15. Effect of the RCA replacement ratio on the longitudinal shear strength of CSRAC composite slabs [67].

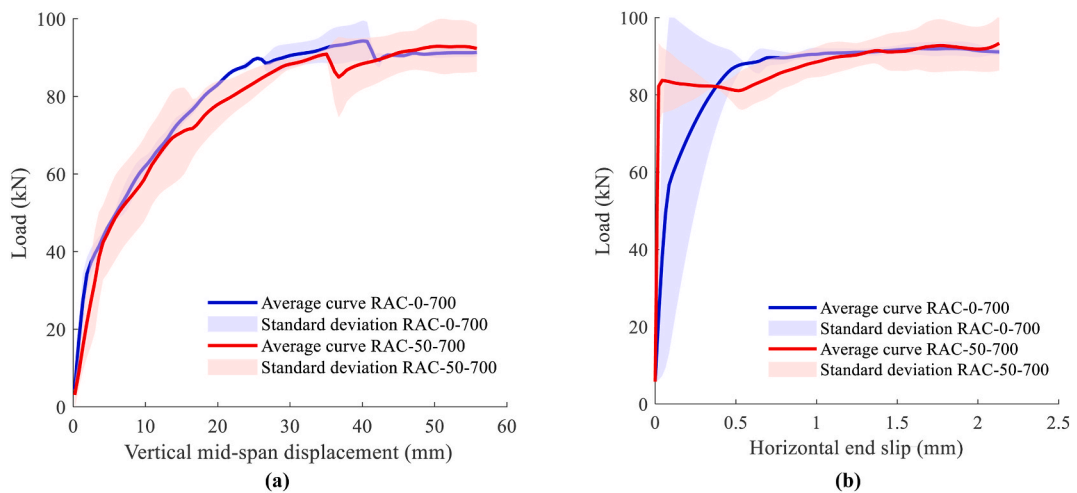


Fig. 16. Load-deformation curve for 700 mm shear span specimens: (a) Load-vertical midspan displacement, (b) Load-horizontal end slip.

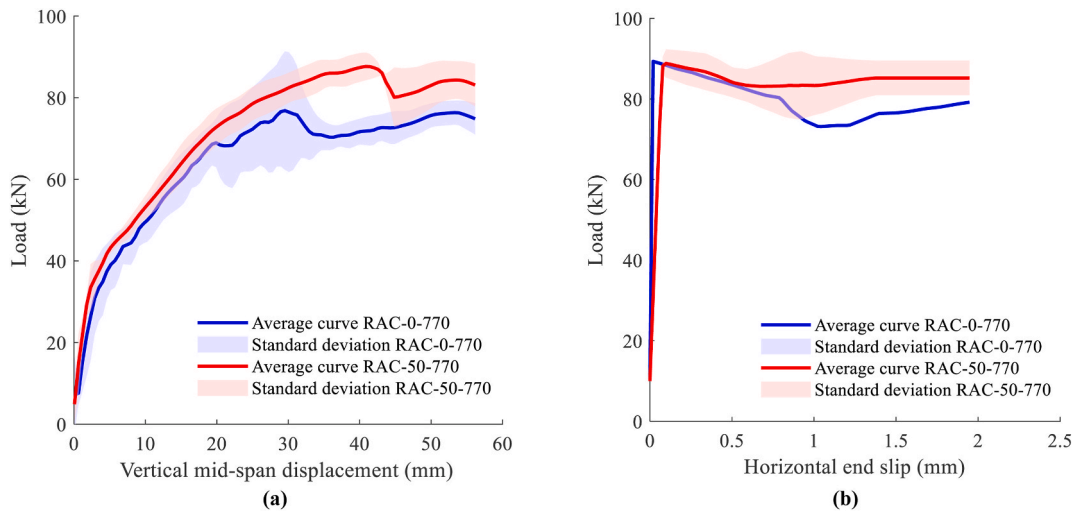


Fig. 17. Load-deformation curve for 770 mm shear span specimens: (a) Load-vertical midspan displacement, (b) Load-horizontal end slip.

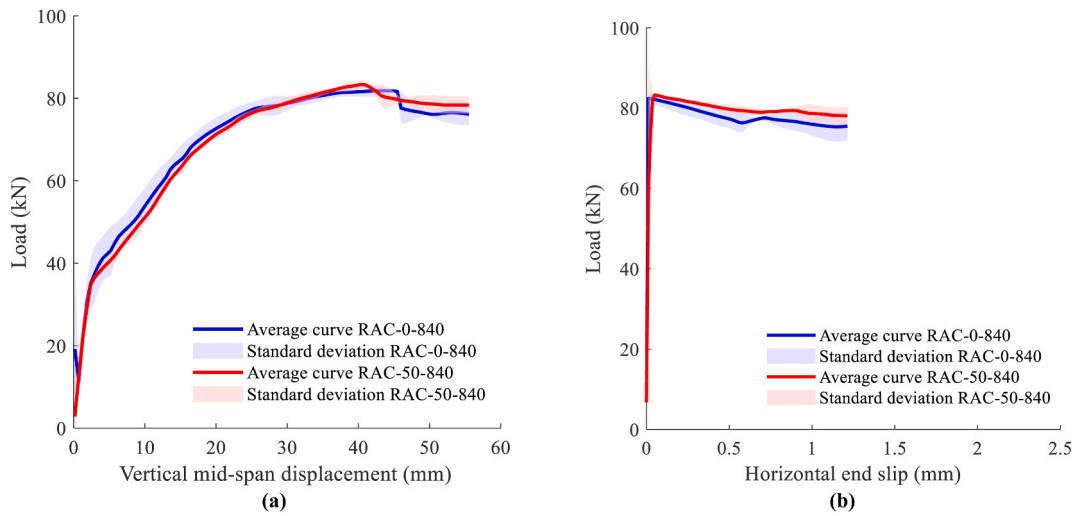


Fig. 18. Load-deformation curve for 840 mm shear span specimens: (a) Load-vertical midspan displacement, (b) Load-horizontal end slip.

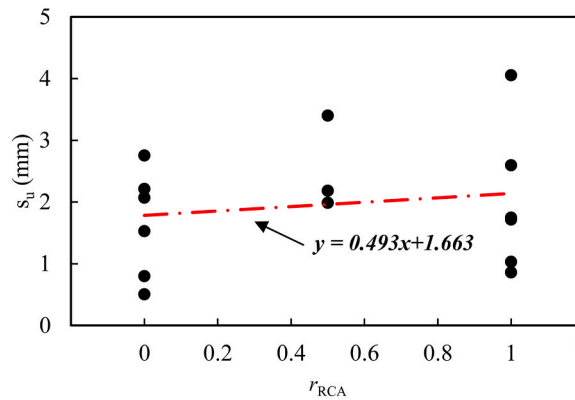


Fig. 19. Influence of r_{RCA} on the s_u .

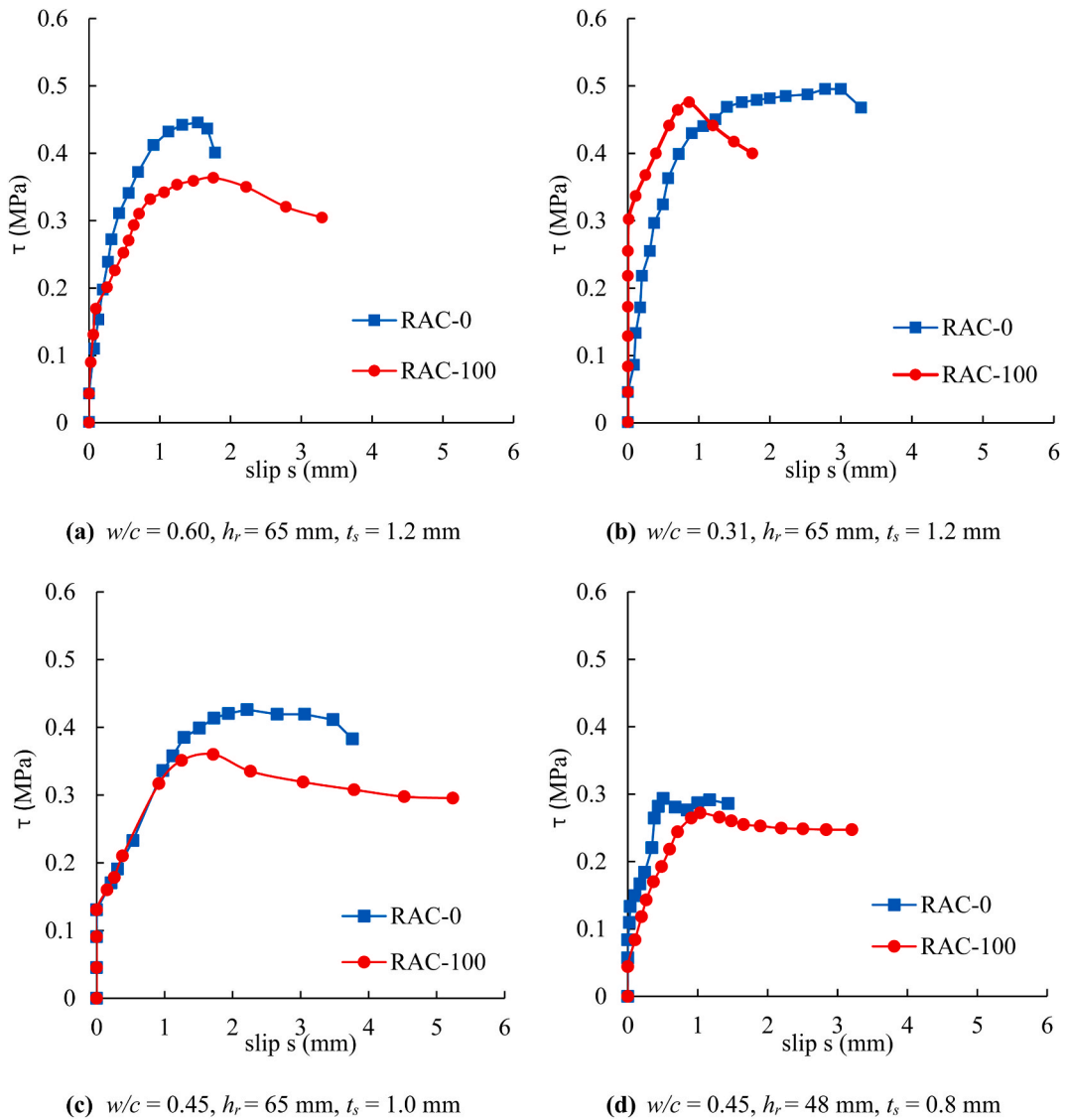


Fig. 20. Influence of r_{RCA} on the τ - s curves [18].

Compared to the previous cases, this study, conducted by Zhang H. et al. [18], focuses on analyzing the interfacial bond behaviour in steel-recycled aggregate concrete (RAC) composite slabs. Pull-out tests were performed on 15 groups of specimens, considering variables such as the replacement ratio of RCA, the water-to-cement ratio (w_c), the profiled steel sheeting thickness (t_s), and the rib height (h_r). The main characteristics of the specimens are summarized in Table 3, while the two steel deck profiles used, DW65 and DW48, are shown in Fig. 12. The experimental procedure is illustrated in the schematic setup shown in Fig. 7. The bond-slip curves obtained were used to analyze the failure mechanisms and the influence of the variables mentioned above. An empirical model for predicting bond-slip behaviour was then developed based on the experimental data.

Table 13
Fitting results for shear bond coefficients of m and k [67].

r_{RCA} (%)	m -value	k -value
0	183.13	0.2808
50	180.59	0.2916
100	177.94	0.3006

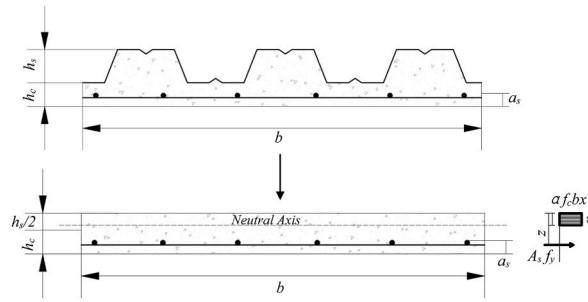


Fig. 21. Equivalent calculation diagram of the lower reinforced concrete bottom slab.

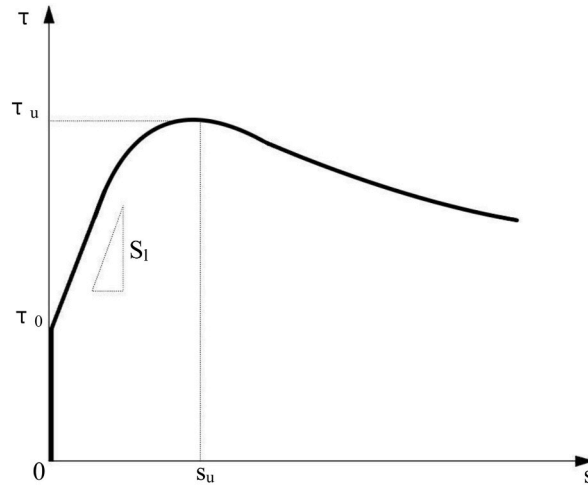


Fig. 22. Typical curve for the interfacial bond-slip relationship of composite slabs.

6.2. Material properties overview

This section provides a comprehensive overview of the material properties used across the analyzed studies, including aggregates' physical and mechanical characteristics, concrete mix proportions, and steel components. The methods employed to determine these material properties, covering both physical and mechanical characteristics, are thoroughly detailed in the referenced articles [18,65,67]. This approach ensures that all data, from mix design to mechanical performance, is framed within standardized testing procedures, enabling accurate comparisons and ensuring reproducibility across studies. The detailed data for each case study is presented below.

In the first study, conducted by Chen B. et al. [67], the physical properties of the recycled concrete aggregates (RCA) and natural aggregates, both coarse (NCA) and fine (NFA), are summarized in Table 4. The concrete mix proportions and basic mechanical properties are outlined in Table 5, while the mechanical properties of the steel components are detailed in Table 6.

The second study, conducted by Lu L. et al. [65], provides information on the mixture ratios and compressive mechanical properties of the Recycled Aggregate Concrete (RAC) in Table 7, while Table 8 outlines the mechanical properties of the profiled steel sheeting and reinforcements. A comprehensive explanation of the methodologies and material testing procedures is also presented in Refs. [62,93] from the same authors.

In the third study, conducted by Zhang H. et al. [18], seven distinct concrete mixes were prepared, with their mix proportions summarized in Table 9. The average values for the elastic modulus (E_s), yield strength (f_y), ultimate tensile strength (f_{tu}), and Poisson's ratio (μ_s) of profiled steel sheeting are presented in Table 10. The characteristics of the aggregates, including NCA, RCA, and sand, are provided in Table 11 and Table 12.

6.3. Mechanical behaviour

Chen B. et al. [67] and Lu L. et al. [65] identified similar failure phenomena in composite slabs during a four-point bending test, characterized by a progression from elastic behaviour to failure, with longitudinal slip and interface debonding as key mechanisms. Initially, the slabs exhibited elastic behaviour, with no visible deformation. As the load increased, cracks appeared, primarily in the concrete near the steel-concrete interface or in the mid-span area. These cracks propagated with further loading, eventually widening

and intensifying near the loading points or along the slab thickness, reaching widths of approximately 0.3 mm in the study by Lu L. et al. [65]. In both cases, the onset of debonding between the concrete and the profiled steel sheeting marked a critical phase. This debonding, coupled with longitudinal slippage, led to a sharp drop in load capacity as the load approached the ultimate value. Further loading caused rapid mid-span deflection, with cracks widening significantly. While Chen B. et al. [67] noted that the use of end anchorages and shear studs improved longitudinal shear capacity, both studies concluded that longitudinal slip and interface debonding remained the dominant failure mechanisms, regardless of the use of RAC.

In the pull-out tests conducted by Zhang H. et al. [18], the bond-slip behaviour (τ - s) progressed through distinct stages. Initially, no visible phenomena occurred, but as the load increased, slips began, marking the failure of the chemical bond. Slips then increased linearly, followed by a nonlinear phase where cracks appeared near the profiled steel deck ribs. Upon reaching the ultimate bond stress (τ_u), the slips increased significantly as the load decreased. Distinct slip values were observed on the everted and embedded sides, with the slips at the embedded edges being much smaller due to the relatively higher bonding strength. This behaviour was attributed to the asymmetric geometry of the composite slab, which induced torsional moments in the concrete. These moments led to penetrating cracks along the slab length and through the deck ribs.

6.4. Load deformation curve

The reviewed studies provide valuable insights into the load-deformation behaviour of composite slabs under various conditions, highlighting critical trends and mechanisms. In the first study by Chen B. et al. [67], the load-mid-span deflection curve and the load-slip curve, shown in Figs. 13 and 14, illustrate the performance of composite slabs with and without end anchorages under varying (r_{RCA}).

Disregarding the initial elastic phase, the increase in load caused bond degradation between the profiled steel sheeting and the concrete, resulting in relative slip and a sharp reduction in load capacity. As the load increased, a progressive stiffness reduction was observed, indicated by the decreasing slope of the curves during the transition to the elastic-plastic phase. Near the ultimate load, the tested CSRAC composite slab presents a hardening behaviour, marking the plastic phase, where the load increased gradually while deflection accelerated significantly. The results indicate that the incorporation of Recycled Concrete Aggregates (RCA) reduces the longitudinal shear capacity of CSRAC composite slabs, with reductions ranging from 2.75 to 4.98 % for a 50 % NCA replacement ratio and 5.55–10.02 % for a 100 % replacement ratio. This reduction is primarily attributed to the residual mortar on the RCA surfaces, which weakens the concrete's tensile strength, promotes cracking, and diminishes shear capacity. Furthermore, slabs with and without end anchorages exhibited similar longitudinal shear strengths after the tests. This outcome is explained by the excessive shear forces that led to connector failure in the anchored specimens, rendering the studs ineffective. Fig. 15 illustrates the influence of the RCA replacement ratio on the longitudinal shear performance of CSRAC composite slabs.

In the second study by Lu L. et al. [65], two experimental tests were performed for each case (RCA-0 and RCA-50), considering different shear spans. To analyze the results, the load-mid-span vertical displacement curves and load-horizontal slip curves, presented in Fig. 16, Fig. 17, and Fig. 18, were interpolated using the Piecewise Cubic Hermite Interpolating Polynomial (PCHIP) method [94]. This approach was chosen due to the high variability in the data, which did not exhibit strictly increasing or decreasing trends. PCHIP is particularly suitable for datasets with peaks or non-uniform variations, as it preserves monotonicity and avoids the oscillations typical of traditional cubic splines. The interpolated data were unified over a common domain, X_{common} , spanning the minimum and maximum values of the original data uniformly. These interpolated curves were subsequently used to calculate mean curves and standard deviation bands, providing a comprehensive visualization of trends and variability. Extrapolation was cautiously performed to estimate values beyond the available range, ensuring consistency and reliability in the analysis. Figs. 16, Fig. 17, and Fig. 18 show that an increase in the span length results in a reduction of the mechanical performance of the superimposed slabs and a higher mid-span vertical displacement, which is the typical behaviour of slabs under bending load. Considering RACCS, the load-vertical mid-span displacement curves show a slight increase in ultimate load compared to NAC slabs, suggesting marginally higher longitudinal shear strength in RACCS. The load-horizontal end slip curves reveal that slip initiates at lower loads as the span length increases and progresses more gradually, indicating greater ductility. This ductile behaviour is further emphasized in RAC slabs, as they exhibit

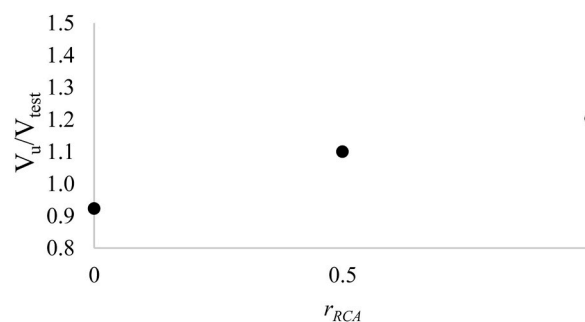


Fig. 23. Ratio between predicted longitudinal shear capacity (V_u) evaluated with Lu L. et al. model's [65] and Chen B. et al.'s [67] experimental data (V_{test}) as a function of (r_{RCA}).

larger slip values under comparable conditions.

Finally, in Ref. [18] by Zhang H. et al., an experimental investigation was undertaken to examine the influence of the recycled concrete aggregate replacement ratio (r_{RCA}) on the bond-slip (τ -s) behaviour of steel-concrete composite slabs. Figs. 19 and 20 derived from the experimental results, provide a detailed representation of the structural performance as a function of r_{RCA} .

Fig. 19 illustrates the relationship between s_u , the slip displacement at the ultimate bond stress, and r_{RCA} , showing a linear increase in s_u as r_{RCA} rises. Slabs with full RCA replacement $r_{RCA} = 100\%$ exhibit an ultimate slip displacement approximately 31% greater than those with $r_{RCA} = 0\%$, reflecting enhanced ductility. This behaviour is linked to the stiffness (S_i) reduction of the τ -s curves, commonly observed in composite slabs with RAC [18]. Fig. 20 illustrates the influence of r_{RCA} and additional parameters, such as water-to-cement ratio (w/c), steel deck rib height (h_r), and steel deck thickness (t_s), on the bond-slip behaviour. From the experimental results, a typical bond-slip (τ -s) curve was obtained, generally characterized by four phases: an initial non-slip stage with no relative movement, a linear elastic phase where bond stress increases proportionally with slip, a nonlinear phase characterized by non-proportional behaviour and the formation of cracks, and a descending phase where bond stress decreases as slip continues to increase. The experimental data confirm that when r_{RCA} increases, the ultimate bond stress (τ_u) decreases, with reductions ranging between 4% and 20% for slabs with full RCA replacement. This reduction is attributed to the weakened mechanical strength of the mortar, caused by a higher water-to-cement ratio (w/c) due to water absorption by the RCA during the mixing process [18].

6.5. Design method for longitudinal shear strength of RACCS

Chen B. et al. [67], starting from the m - k method, explored the calculation of longitudinal shear strength for steel-concrete composite slabs and provided insights into the influence of key parameters on their performance. The Chinese code JGJ 138–2016 [95] proposes an Eq. (8) to evaluate the shear capacity of profiled steel-concrete composite slabs.

$$\frac{V_u}{bhf_t} = m \frac{A_p}{1.25L_sbf_t} + k \tag{8}$$

where V_u represents the shear capacity of the composite slab, b is the width of the composite slab, h is the effective height of the composite slab cross-section, f_t is the design value of the axial tensile strength of concrete, A_p is the cross-sectional area of the profiled steel sheeting, L_s is the shear span length, and m and k are the shear bond coefficients. The difference in tensile behaviour between Recycled Aggregate Concrete (RAC) and Natural Aggregate Concrete (NAC) can be attributed to the presence of residual mortar on the recycled aggregates. This leads to RAC exhibiting slightly higher tensile strain, as demonstrated in Ref. [96]. For this reason, Xiao et al. [96] proposed a tensile stress-strain model that incorporates the RCA replacement ratio, providing a more accurate method for predicting the performance of CSRAC composite slabs. By integrating the m - k method with these tensile strain models, a comprehensive approach was developed for calculating the longitudinal shear strength of steel-concrete composite slabs with end anchorages. The model is based on the previous Eq. (8), which captures the geometric and material properties of the composite slab but does not consider the influence of shear studs. To address this limitation, Nie J.G. et al. [97] introduced a refined formulation that incorporates the contributions of shear studs and the concrete compression zone, significantly improving the prediction of composite behaviour. Considering also this contribution, Xiao et al. [96] proposed the following Eq. (9):

$$\frac{V_u}{bhf_t} = m \frac{A_p}{1.25L_sbf_t} + k + 0.5 \frac{n N_v^c \left(\frac{h-x}{2} \right)}{L_s bhf_t} \tag{9}$$

Table 13, taken from Chen B. et al. [67], shows that when the RCA replacement ratio (r_{RCA}) increases, the m -value decreases, indicating reduced mechanical interlock between the corrugated steel and concrete. Conversely, the k -value increases by 3.85% at a 50% replacement ratio and by 7.05% at a 100% replacement ratio, reflecting enhanced frictional interaction. Based on these findings, a design method for calculating the longitudinal shear capacity of CSRAC composite slabs was developed, incorporating the RCA replacement ratio (r_{RCA}) based on the m - k method, as detailed in Eq. (10).

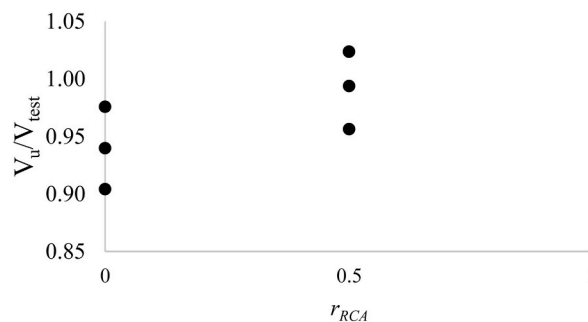


Fig. 24. Ratio between predicted longitudinal shear capacity (V_u) evaluated with Chen B. et al. model's [67] and Lu L. et al.'s [65] experimental data (V_{test}) as a function of (r_{RCA}).

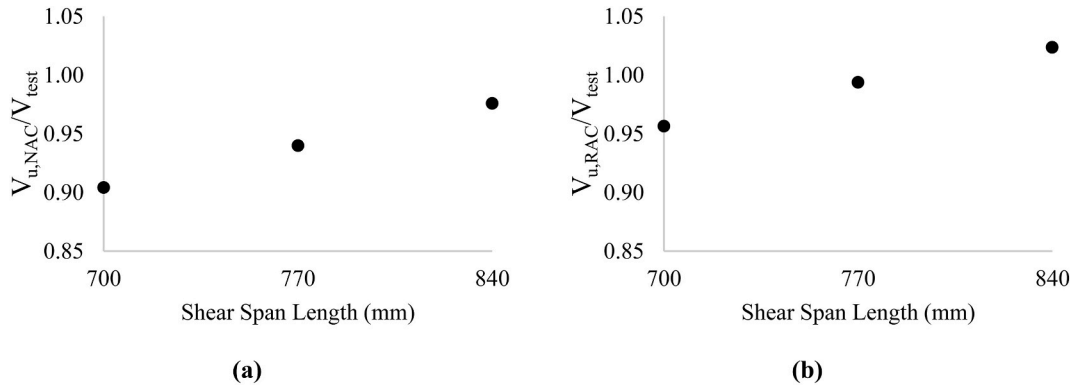


Fig. 25. Ratio of predicted longitudinal shear capacity (V_u) evaluated with Chen B. et al. model's [67] and Lu L. et al. [65] experimental data (V_{test}) as a function of the shear span length in (a) NAC composite slab, (b) RAC composite slab.

$$\frac{V_u}{bhf_t} = \alpha m_N \frac{A_p}{1.25L_s b f_t} + \beta k_N + 0.5 \frac{nN_v^c \left(h - \frac{x}{2}\right)}{L_s b h f_t} \quad (10)$$

$$\alpha = (1 - 0.0284 r_{RCA}) \quad (10.a)$$

$$\beta = (1 + 0.0705 r_{RCA}) \quad (10.b)$$

where, m_N and k_N represent the shear bond coefficients of corrugated steel-natural concrete composite slabs, α and β are correction factors used to modify these coefficients to reflect the influence of the RCA replacement ratio, denoted by r_{RCA} .

In the second study by Lu L. et al. [65], the superimposed slab is conceptually divided into two parts to better analyze the behaviour of each slab and to understand the experimental failure phenomena depicted in Figs. 16, Fig. 17, and Fig. 18. Based on this approach, the longitudinal shear capacity of the superimposed slab (V_{ud}) is expressed in Eq. (13), where V_{ud1} is the shear resistance of the upper reinforced concrete slab and V_{ud2} is the shear resistance of the lower composite bottom slab.

$$V_{ud} = b h_0 \left(\frac{m A_p}{b L_s} + k \right) + \frac{A_p f_y \left(2h_c + h_s - 2a_s - \frac{A_p f_y}{1.25f_t b} \right)}{L_s} \quad (11)$$

The first term of Eq. (11) represents the shear resistance of the upper composite slab determined using the m - k method, see Eurocode 4 [27]. In Eq. (11), b is the width of the upper composite slab, h_0 is the maximum thickness of the superimposed surface concrete, A_p is the cross-sectional area of the steel deck within width b , and L_s is the shear span. The values of m and k were experimentally determined to be 93.65 N/mm² and 0.0995 N/mm², respectively. The second term of Eq. (11) accounts for the shear resistance of the lower reinforced concrete bottom slab. This value is derived by establishing a moment equilibrium equation at the ultimate limit state. For the sake of simplicity, the reinforced concrete bottom slab with concave and convex openings is approximated as an equivalent rectangular slab, as illustrated in Fig. 21, where there is the definition of the remaining symbols is given in Eq. (11).

Finally, in the third study conducted by Zhang H. et al. [18], a design approach was developed to estimate the longitudinal shear properties of composite slabs by characterizing the interfacial behaviour. A bond-slip relationship model was considered suitable for slabs incorporating re-entrant steel sheeting.

Fig. 22 illustrates a typical interfacial bond-slip relationship, derived from the interpretation of experimental data and the failure phenomena observed during testing, as shown in Fig. 20. The curve is expressed in Eq. (12), where the damage evolution coefficient k represents the progressive stages of interfacial damage and can be determined using Eq. (13).

$$\tau = \begin{cases} \tau & (0 \leq \tau \leq \tau_0) \quad s = 0 \\ \tau_0 + (1-k)S_1 s & s > 0 \end{cases} \quad (12)$$

$$k = \begin{cases} 1 - \frac{\rho n}{n-1 + x^n} & x \leq 1 \\ 1 - \frac{\rho}{\alpha(x-1)^2 + x} & x > 1 \end{cases} \quad (13)$$

The parameters ρ , n , and x are dimensionless variables related to key features of the bond-slip curve, including τ_0 (MPa), τ_u (MPa), S_1 (MPa/mm), and s_u (mm). These parameters are calculated using Eqs. (14)–(17). Additionally, the parameter α , representing the descending branch of the bond-slip relationship, is determined through Eq. (17).

$$\rho = \frac{\tau_u - \tau_0}{S_l s_u} \quad (14)$$

$$n = \frac{S_l s_u}{S_l s_u - \tau_u + \tau_0} \quad (15)$$

$$x = \frac{s}{s_u} \quad (16)$$

$$\alpha = (4.7 f_c^{0.04} - 3.7)(1 + 0.32 r_{RCA}) \left(\frac{h_r}{20} - 2.2 \right) \quad (17)$$

The expressions for τ_0 , τ_u , S_l , and s_u were established based on the experimental results, incorporating the effects of several key variables, including the compressive strength of NAC (f_c , MPa), the RCA replacement ratio (r_{RCA} , %), the steel deck thickness (t_s , mm), and the rib height (h_r , mm). These dependencies are expressed in Eqs. (19)–(22).

$$\tau_0 = \frac{f_c^{0.5}}{125} (-0.3 + 1.5 t_s) \left(1 + \frac{h_r}{65} \right) \quad (19)$$

$$\tau_u = \frac{f_c^{0.5}}{200} (1 + 4.1 t_s) \left(1.2 + \frac{h_r}{65} \right) (1 - 0.12 r_{RCA}) \quad (20)$$

$$S_l = \frac{f_c^{0.11}}{4} (0.3 + 1.1 t_s) \left(1.6 \frac{h_r}{65} \right) (1 - 0.11 r_{RCA}) \quad (21)$$

$$s_u = \frac{f_c^{1.6}}{17} \left(0.16 + \frac{t_s}{40} \right) \left(-0.6 + \frac{h_r}{65} \right) (1 + 0.18 r_{RCA}) \quad (22)$$

7. Discussion

The longitudinal shear performance of the Recycled Aggregate Concrete Composite Slab (RACCS) is significantly influenced by the presence of Recycled Concrete Aggregate (RCA). The analysis of three case studies [18,65,67], presented in Section 6, underscored the recycled concrete aggregate replacement ratio (r_{RCA}) as a pivotal factor for the structural behaviour of composite slabs. A key factor is the residual mortar present on RCA, which contributes to higher concrete porosity, reduced tensile strength, and a weakened mechanical bond between the concrete and the profiled steel sheeting.

All the considered composite slabs present a similar failure mechanism, where the ductile flexural failure is typically anticipated by a brittle longitudinal shear behaviour collapse. This brittleness is characterized by a clear loss of mechanical performance due to debonding between steel and concrete, which can occur even at relatively low loads when r_{RCA} is high. However, the use of RAC seems to improve the system's overall ductility, as indicated by the smoother softening branch of the τ - s curves, reflecting enhanced energy dissipation capacity. The load-deformation curves, as analyzed in both Chen B. et al. [67] and Lu L. et al. [65], reveal important trends. In the study by Chen B. et al. [67], an increase in r_{RCA} results in earlier slip and larger ultimate slip values, leading to reduced longitudinal shear strength but improved ductility. In contrast, Lu L. et al. [65] demonstrate that at moderate r_{RCA} levels, such as 50 %, the longitudinal shear strength of RACCS can exceed that of NACCS under comparable conditions. However, even in this case, as the shear span length increases, the longitudinal shear strength of RACCS decreases. Additionally, RACCS in both studies demonstrate a higher ultimate slip and a reduced slope in the load-deformation curve at r_{RCA} increased, indicating enhanced ductility. This response can be attributed to two interacting mechanisms that fundamentally modify the interfacial transfer process. Firstly, the weaker ITZ and higher porosity of RAC favour early formation of microcracks around the embossments of the steel decking. These microcracks allow relative slip to initiate earlier but evolve gradually, preventing abrupt debonding and sudden loss of load capacity. Secondly, the intrinsic roughness and angularity of RCA particles, although associated with weaker chemical adhesion, enhance frictional resistance once slip occurs, allowing residual interfacial stress transfer to persist over larger slips and contributing to a more energy-dissipative post-peak behaviour [98]. As a result, while the initial bond degradation occurs earlier, the post-peak load-displacement rate is lower compared to NAC ones, modifying the overall ductility and failure mode of the slab.

Future parametric analysis is essential to deepen the understanding of the variables influencing the behaviour of RACCS. Identifying the most critical parameters and assessing their combined effects will not only enhance design efficiency but also promote greater sustainability and reliability in the use of RAC in modern construction. Key parameters that should be considered are.

- i. Water-to-cement ratio (w/c): this parameter significantly influences the quality and porosity of the cementitious matrix, impacting the mechanical strength and durability of concrete. A high w/c ratio amplifies the negative effects of the r_{RCA} on steel-concrete bond strength, especially when using RCA with high absorption capacity, as it promotes the formation of a less compact paste-aggregate interface and increases the likelihood of microvoids leading to increased porosity and a weakened mechanical bond. These microcracks tend to nucleate and propagate around the embossments of the profiled steel sheeting under early-age shrinkage or mechanical loading, facilitating premature slip initiation at the interface. In the analyzed studies,

the w/c ratio ranged from 0.31 to 0.60, with an optimal range of 0.40–0.45 to balance workability and mechanical performance in mixes with high RCA content. Ratios above 0.50–0.60 were particularly detrimental, leading to a highly porous concrete with a weaker ITZ. These limitations highlight the need for corrective measures when using RCA, such as pre-saturating aggregates to reduce water demand, employing water-reducing admixtures or supplementary cementitious materials to refine pore structure, and adopting optimized mix designs that maintain a lower effective w/c ratio while ensuring adequate workability. Without such adjustments, the combined effect of RCA porosity and high-water content produces an interface unable to ensure consistent mechanical interlock, thereby undermining the longitudinal shear performance of RACCS [99].

- ii. Profiled steel sheeting geometry: the geometric configuration of the steel sheeting, particularly rib height (h_r) and plate thickness (t_s), plays a crucial role in stress transfer and system stability. Experimental observations indicate that taller ribs (60–75 mm) generally improve mechanical interlocking, allowing higher load transfer by providing a greater embedded area and resisting longitudinal shear failure. However, when RAC is used, the presence of a porous matrix and weaker ITZ covering the embossments makes this mechanical interlock less effective. Higher ribs lead to increased stress concentrations around the embossment edges, which can trigger premature microcracking in the concrete. These cracks tend to propagate quickly, facilitating early debonding despite the apparent mechanical anchorage. Thin sheets (≤ 0.8 mm) may suffer from local deformations or warping under concentrated forces, further reducing the effectiveness of interlock and bond transfer. On the other hand, increasing the sheet thickness enhances both the structural stiffness and the overall tensile resistance of the composite slab due to the higher steel content. However, it has only a marginal influence on bond quality when the steel-concrete adhesion is already compromised by the weak ITZ associated with RCA. Case studies indicate that when taller ribs and thinner plates are combined with a low water-to-cement ratio, RACCS can even exhibit higher ultimate bond stresses than NACCS under comparable conditions. Trapezoidal or V-shaped profiles have demonstrated superior performance compared to straight or parallel-walled corrugated profiles because their inclined rib surface provides a larger contact area between steel and concrete, enhancing both frictional resistance and the transfer of tangential stresses along the interface. The sloped rib geometry creates a wedge effect, whereby the concrete, under loading, is progressively locked against the inclined rib walls. This interaction triggers passive confinement forces, delaying slip initiation and enhancing the longitudinal shear transfer mechanism. In contrast, profiles with nearly vertical sides tend to fail by detaching an entire block of concrete once debonding starts, leaving minimal residual interlock to mobilize and resulting in a sudden and more brittle loss of shear transfer capacity [100]. These findings highlight rib height and shape profile as a more critical factor than plate thickness in governing the overall composite slab behavior.
- iii. Mechanical properties of concrete: key factors such as tensile strength and elastic modulus significantly influence the overall behaviour of the slab, whereas compressive strength has shown a negligible impact on structural performance in the case studies. Tensile strength is critical for preventing debonding at the steel-concrete interface and ensuring efficient load transfer.
- iv. Steel-concrete interface parameters: the case studies indicate that the initial chemical bond strength (τ_0) has a negligible impact on structural behaviour, as performance remains consistent until this value is reached across all analyzed cases. Conversely, factors such as the initial stiffness of the τ -s curve, which decreases by 8 %–16 % with higher r_{RCA} , and the post-failure behaviour, where ductility improves with a 22 % increase in maximum slip, are critical. Future parametric analyses should, therefore, focus on initial stiffness and post-failure ductility rather than τ_0 , which remains relatively uniform across configurations.

A critical aspect is the importance of advanced design methods to predict and enhance the structural behaviour of RACCS. The comparative analysis of traditional design models has revealed significant limitations in their application to RACCS. These models, originally developed for Natural Aggregate Concrete (NAC), fail to adequately account for the distinctive characteristics of Recycled Concrete Aggregates (RCA). In light of these findings, the available analytical models were thoroughly examined, including the modified m - k methods for predicting the longitudinal shear capacity of RACCS.

The comparative analysis of analytical models further emphasizes the distinct behaviour of RACCS. Both Chen B. et al. [67] and Lu L. et al. [65] observed that the slope (m) of the linear regression in the m - k method decreases with increasing r_{RCA} , while the intercept (k) tends to increase. This trend reflects a shift from a mechanical interlock-dominated longitudinal shear transfer, typical of NAC, to a mechanism where friction plays a more significant role after initial bond degradation. However, current empirical formulations, originally derived from tests on conventional concrete, do not represent these variations, and the physical meaning of m and k under the influence of recycled aggregate remains unclear. The strong sensitivity of these parameters to mix properties and experimental setup introduces significant variability in predicted longitudinal shear capacities, raising concerns about the reliability of the direct application of NAC-based design methods to RACCS.

In this review, two analytical models developed by Chen B. et al. [67] and Lu L. et al. [65], both designed to estimate the longitudinal shear strength (V_u) in RACCS, have been compared. The primary objective was to investigate whether the experimental parameters, such as the m - k coefficients derived from one model, could be directly applied within the framework of the other, or if their use was inherently context-dependent. Indeed, m and k are not universal constants but depend on the specific experimental conditions under which they are derived. This dependency makes direct comparisons of the models quite complex, as each set of coefficients reflects unique conditions, making them non-transferable without adjustments. To address this challenge, this analysis employed a cross-application of m - k coefficients between the two models. The longitudinal shear strength (V_u) was calculated using each model while substituting the coefficients derived from the other, and the theoretical predictions were compared against experimental data.

A selection criterion for the samples was established to ensure the validity of the comparison and the proper adaptation of the model formulation to the specific case study. This was necessary because the second model, presented in Eq. (11) by Lu et al. [65], does

not explicitly account for the presence of end anchorages. Consequently, the comparison was conducted exclusively on the case of Corrugated Steel Recycled Aggregate Concrete composite slabs without end anchorage (CSRAC-N), as the inclusion of anchorages would have required the addition of a specific term, as highlighted in the formulation of the first model in Eq. (10) by Chen B. et al. [67]. Conversely, the second model in Eq. (11) [65] incorporates the contribution of the superimposed bottom slab, which, being absent in the specimens tested by Chen B. et al. [67], led to the consideration of only the first term of Eq. (11).

Refer to Fig. 23 for a summary of the comparative analysis between Lu et al.'s model [65] (V_u) and experimental data (V_{test}) from Chen B. et al. [67]. The V_u exhibited an unexpected increasing trend, accompanied by a rise in errors relative to the experimental values as the r_{RCA} increased. However, in the case of CSRAC-N-0, the predicted V_u closely matched the experimental results. This alignment highlights the model's suitability for ordinary concrete with natural aggregates (NAC), where recycled aggregates (RCA) are absent. However, its accuracy diminishes significantly with higher RCA content, overestimating V_u by up to 20 % despite adjustments using mix-specific m - k coefficients derived by Chen B. et al. [67]. This indicates the model's limited ability to account for the complex mechanical behaviour introduced by RCA.

Indeed, Lu et al.'s model, as a formulation of the m - k method, shares these limitations, as it does not incorporate adaptations to address the unique properties of RCA, confirming what was discussed in the prior sections. While it demonstrates limited applicability, it can still be effectively used for ordinary concrete with natural aggregates (NAC).

While, according to Figs. 24 and 25, the second model proposed by Chen B. et al. [67] demonstrates a greater capacity to represent Lu L. et al.'s experimental V_{test} data [65]. The tensile strength of concrete (f_t) in Eq. (10) was calculated according to Eurocode 2 [101], ensuring consistency in the evaluation process.

Chen B. et al.'s model in Eq. (10), while based on the m - k method, has been explicitly adapted and modified to account for the influence of recycled aggregates within the mix design. This enhancement extends its applicability beyond ordinary concrete with natural aggregates (NAC) to also include concrete incorporating recycled concrete aggregates (RCA).

After this comparison, a common observation highlights a critical limitation. Despite applying a safety factor of 1.25, the theoretical results closely match the experimental data, raising concerns about the model's ability to provide an adequate safety margin. Real-world uncertainties, such as material variability and unpredictable loads, require a greater margin for deviations.

Overall, the reviewed evidence demonstrates that the use of RAC does not merely lead to a reduction in peak longitudinal shear strength but alters the fundamental mechanism governing interfacial load transfer in composite slabs. RACCS exhibits earlier slip than NAC counterparts, caused by a weaker interfacial transition zone, increased porosity, and premature microcrack formation around embossments. However, once slip starts, failure progresses more gradually, sustained by frictional resistance activated by the rougher, more angular RCA surface texture, resulting in a higher residual bond capacity and improved post-peak ductility. These findings confirm that the behaviour of RACCS cannot be reliably represented by the current empirical m - k formulations, which were originally developed for NAC and assume empirical coefficients from experimental calibration, independent of aggregate quality, mix design, or the altered micromechanical mechanism introduced by RCA. While the m - k method indirectly considers deck geometry through the effective cross-section area, it does not account for the specific load-transfer mechanism activated by inclined rib walls in trapezoidal or re-entrant profiles. Profiles with similar contact area but different wall inclinations can exhibit markedly different post-slip resistance, as inclined ribs lead to additional confinement forces that delay block detachment and enhance frictional transfer [83].

A critical limitation highlighted by this review is the large variability in experimental results among studies, partly due to RCA heterogeneity but also to non-standardized test methodologies. Differences in specimen geometry, anchorage details, and loading procedures, combined with the frequent absence of statistical reliability due to the number of specimens tested, undermine the ability to establish consistent and reproducible trends for m and k parameters. Moreover, the lack of complementary analyses using the Partial Shear Connection Method (PSM) to directly evaluate slip stresses (τ) and compare bond-slip trends prevents a more robust understanding of interfacial behaviour. This lack of methodological harmonization reduces the reliability of empirical coefficients derived from NAC and questions their direct applicability to RACCS, where altered micromechanical mechanisms further increase uncertainty in longitudinal shear predictions.

Despite these discrepancies, two distinct behavioural ranges can be identified. At $r_{RCA} \leq 50\%$, the interface response remains primarily mechanical interlock-driven, with limited reductions in initial stiffness and peak longitudinal shear strength compared to NACCS. Above 50% r_{RCA} , the ITZ becomes significantly more porous, microcracks appear earlier around embossments, and the dominant mechanism shifts progressively towards frictional slip, resulting in earlier bond degradation but higher ductility and energy dissipation. The exact threshold value at which this transition occurs remains unknown, due to the limited number of intermediate replacement ratios tested. A broader number of concrete mixes with additional replacement levels is therefore essential to identify this shift accurately and to calibrate future predictive models.

To address this gap, a more mechanical interpretation of the m and k parameters is necessary. Rather than treating them as fixed empirical coefficients, they should be expressed as functions of RCA content, water-to-cement ratio and steel deck profile type, which collectively control ITZ quality, interlock efficiency and post-bond frictional resistance. The introduction of correction factors would allow distinguishing the relative contributions of mechanical interlock and friction to overall longitudinal shear resistance.

- i. α ($\% r_{RCA}, w/c$) quantifies the progressive loss of mechanical interlock efficiency with increasing RCA content and its sensitivity to mix porosity, as higher w/c values accelerate microcracking and weaken cohesive bond around embossments.
- ii. β ($\% r_{RCA}, w/c$) represents the residual shear transfer capacity mobilized by frictional resistance once bond degradation occurs, capturing how surface roughness of RCA particles and mix quality sustain post-peak load transfer.

- iii. γ accounts for the influence of rib geometry and inclination, differentiating profiles that activate passive confinement and wedge mechanisms (e.g., trapezoidal, re-entrant) from those with parallel walls, which tend to experience more abrupt block detachment despite similar contact area.

Defining such correction laws cannot rely on isolated datasets with sparse replacement ratios and inconsistent methodologies. A large-scale, systematic parametric investigation is required, combining harmonized experimental campaigns with accurate finite element simulations able to reproduce microcrack formation, local stress redistribution, and post-peak frictional mechanisms. This approach should explore a denser range of RCA contents, particularly in the 30–70 % range, together with variations in mix properties and deck geometry, to map the transition between interlock and friction-dominated behaviour. The resulting dataset would enable multi-variable regression and surrogate modelling, produce reliable correction factor laws, and identify optimal combinations of material and geometric parameters that maximize both peak longitudinal shear strength and ductility.

Building on this foundation, the proposed methodology could evolve into a next-generation, code-calibrated predictive tool, replacing empirical coefficients with rational, physically justified laws capable of accurately predicting m and k in RACCS. This evolution is essential to close the gap between experimental observations and design practice, enabling engineers to design RACCS structures without unsafe simplifications or excessive conservatism. It would also allow the integration of complementary approaches such as the Partial Shear Connection Method (PSM), providing a more direct evaluation of slip stresses and enabling consistent comparisons between predicted and observed bond–slip behaviour. Such developments would pave the way for evidence-based provisions in future Eurocode revisions, establishing a more reliable and physics-based informed design framework for RACCS.

8. Conclusion

In this paper, integrated methodologies were reviewed to investigate the longitudinal shear behaviour of RACCS. The study presents a comprehensive synthesis of experimental findings, analytical models, and design approaches, with the primary aim of examining how the recycled concrete aggregate replacement ratio (r_{RCA}) influences mechanical performance, focusing on the concrete–steel plate interface and overall structural parameters.

The review adopts a systematic methodology based on PRISMA guidelines [34], enhanced by advanced text-mining techniques to systematically map existing research, identify prevailing trends, and highlight critical knowledge gaps in the field. The analysis encompasses experimental investigations, including full-scale bending tests and detailed bond–slip measurements, aimed at evaluating the longitudinal shear response of RACCS under different loading and material conditions. In parallel, existing design provisions for longitudinal shear strength in composite slabs originally developed for natural aggregate concrete (NAC) are examined to assess their validity and limitations when applied to RACCS. The study also synthesizes available analytical modelling approaches, with particular emphasis on modified m – k methods and interfacial bond–slip formulations, providing a comparative overview of their predictive capabilities and applicability to RACCS design.

The text-mining analysis provided deeper insights into the current research landscape on RACCS. Although interest in sustainable construction materials is steadily increasing, the keyword distribution revealed that most investigations still concentrate on compressive strength, flexural behaviour, and general mechanical properties of RAC, with comparatively few studies dedicated to longitudinal shear transfer and interfacial mechanisms. This imbalance was further emphasized by the scarcity of RACCS-focused publications within the broader pool of research on composite slabs. Keyword clustering highlighted inconsistent terminology, a lack of harmonized descriptors, and limited cross-study comparability, largely due to the absence of standardized experimental protocols. Network analysis of co-occurring terms also exposed a critical research gap: three dedicated design methodologies or bond–slip constitutive laws specifically calibrated for RACCS currently exist. The fragmentation of available datasets, particularly at higher r_{RCA} , significantly restricts the development of reliable predictive models that can capture key microstructural effects such as residual mortar layers, increased porosity, and degradation of the Interfacial Transition Zone (ITZ), all of which directly govern interfacial mechanical bond and frictional resistance. Moreover, the existing literature often reports contradictory findings on the influence of RCA content on longitudinal shear strength. While some studies consistently show a progressive reduction in longitudinal shear capacity with increasing r_{RCA} , others suggest that enhanced mechanical interlock or surface roughness can partially offset the lower intrinsic quality of RCA. These discrepancies underline the strong interaction between multiple parameters, including residual mortar thickness, water-to-cement ratio, and steel deck geometry, that are seldom investigated in a combined and systematic manner, leaving substantial uncertainty regarding their coupled effects on the longitudinal shear behaviour of RACCS.

Beyond experimental and parametric investigations, the advancement and implementation of innovative design approaches are essential to predict and enhance the structural behaviour of RACCS. Analytical modelling approaches also exhibit substantial limitations. The widely used m – k method, originally developed for NAC, lacks physical calibration for RACCS, leading to potentially unsafe or overly conservative predictions of longitudinal shear resistance. A comparative analysis of available models revealed significant variability in both their accuracy and range of applicability, underscoring the absence of a unified, reliable framework for RACCS. These discrepancies highlight the need for advanced analytical formulations explicitly grounded in a micromechanical understanding of the RCA on longitudinal shear behaviour in composite slab applications. Future models should capture the progressive loss of adhesion, the reduction and variability of frictional resistance, and the altered mechanical interlock mechanisms that emerge at different RCA contents, ensuring a more reliable prediction of longitudinal shear transfer in RACCS.

Research efforts need to move beyond isolated experimental datasets and simplistic empirical calibrations toward the creation of a rational, physically informed predictive framework for RACCS. Instead of treating the coefficients m and k as fixed empirical parameters, upcoming analytical approaches should express them as functions of key variables, including RCA replacement ratio, water-

to-cement ratio, and steel deck profile geometry, that collectively govern ITZ quality, interlock efficiency, and post-bond frictional resistance. Introducing appropriate correction factors would enable a mechanistic decomposition of longitudinal shear resistance into its primary contributors, improving both accuracy and physical consistency in design predictions.

Developing reliable models requires coordinated experimental campaigns with harmonized protocols, expanded RCA content ranges (particularly 30–70 %), and systematic variation of mix parameters and steel deck geometries. These efforts, combined with high-fidelity finite element simulations capturing microcrack initiation, stress redistribution, and post-peak frictional mechanisms, would provide the comprehensive datasets needed for multi-variable regression and surrogate modelling. Such a foundation would pave the way for next-generation, code-calibrated predictive tools that replace empirical simplifications with mechanistically derived functions, enabling more accurate, non-conservative design predictions, integration with approaches like the Partial Shear Connection Method (PSM), and evidence-based updates to Eurocode provisions, ultimately bridging the gap between experimental evidence and safe, sustainable design practice for RACCS.

Finally, while existing studies provide valuable insights into the structural behaviour of composite slabs incorporating recycled aggregates, the current body of knowledge remains fragmented and fails to deliver a coherent understanding of the complex interactions among critical parameters. This lack of integration not only constrains theoretical understanding but also prevents the formulation of robust, code-compliant design recommendations, ultimately slowing down the safe and sustainable adoption of RAC in real-world composite slab applications. By systematically consolidating the available evidence and highlighting the most critical knowledge gaps, this review sets the foundation for future research and the development of improved analytical and experimental frameworks that can reliably guide the use of RACCS.

CRedit authorship contribution statement

Marta Saccone: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Data curation. **Flavio Stochino:** Writing – review & editing, Validation, Supervision, Funding acquisition, Formal analysis. **Marco Zucca:** Writing – review & editing, Validation, Formal analysis. **Marco Simoncelli:** Writing – review & editing, Validation, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The financial support of project SARCOS PRIN2022 – CUP: F53D23002030006 - Prot. 2022WWN3TC is acknowledged.

Data availability

Data will be made available on request.

References

- [1] S.D. Datta, M.H.R. Sobuz, A.S.M. Akid, S. Islam, Influence of coarse aggregate size and content on the properties of recycled aggregate concrete using non-destructive testing methods, *J. Build. Eng.* 61 (2022) 105249, <https://doi.org/10.1016/j.jobbe.2022.105249>.
- [2] K. Hu, S.T.A. Gillani, X. Tao, J. Tariq, D. Chen, Eco-friendly construction: integrating demolition waste into concrete masonry blocks for sustainable development, *Constr. Build. Mater.* 460 (2025) 139797, <https://doi.org/10.1016/j.conbuildmat.2024.139797>.
- [3] D. Lu, F. Qu, C. Zhang, Y. Guo, Z. Luo, L. Xu, W. Li, Innovative approaches, challenges, and future directions for utilizing carbon dioxide in sustainable concrete production, *J. Build. Eng.* 97 (2024) 110904, <https://doi.org/10.1016/j.jobbe.2024.110904>.
- [4] B. Wang, L. Yan, Q. Fu, B. Kas, A comprehensive review on recycled aggregate and recycled aggregate concrete, *Resour. Conserv. Recycl.* 171 (2021) 105565, <https://doi.org/10.1016/j.resconrec.2021.105565>.
- [5] G. Terán-Cuadrado, F. Tahir, A. Nurdiawati, M.A. Almarshoud, S.G. Al-Ghamdi, Current and potential materials for the low-carbon cement production: life cycle assessment perspective, *J. Build. Eng.* 96 (2024) 110528, <https://doi.org/10.1016/j.jobbe.2024.110528>.
- [6] M. Zhao, Y. Wang, D.E. Lehman, Y. Geng, C.W. Roeder, Response and modeling of axially-loaded concrete-filled steel columns with recycled coarse and fine aggregate, *Eng. Struct.* 234 (2021) 111733, <https://doi.org/10.1016/j.engstruct.2020.111733>.
- [7] Z. Liu, S. Liu, K. Takasu, Y. Zhang, Y. Wang, H. Suyama, Development of sustainable self-compacting concrete: replacement of sand with municipal solid waste incineration ash molten slag and recycled fine aggregate, *Constr. Build. Mater.* 450 (2024) 138674, <https://doi.org/10.1016/j.conbuildmat.2024.138674>.
- [8] H. Le, Q. Bui, Recycled aggregate concretes – a state-of-the-art from the microstructure to the structural performance, *Constr. Build. Mater.* 257 (2020) 119522, <https://doi.org/10.1016/j.conbuildmat.2020.119522>.
- [9] V.W. Tam, M. Soomro, A.C.J. Evangelista, A review of recycled aggregate in concrete applications (2000–2017), *Constr. Build. Mater.* 172 (2018) 272–292, <https://doi.org/10.1016/j.conbuildmat.2018.03.240>.
- [10] J. Pacheco, J. De Brito, C. Chastre, L. Evangelista, Recycled concrete for structural applications. *Recycled Concrete*, Elsevier, 2023, pp. 195–231, <https://doi.org/10.1016/B978-0-323-85210-4.00011-4>.
- [11] G. Bai, C. Zhu, C. Liu, B. Liu, An evaluation of the recycled aggregate characteristics and the recycled aggregate concrete mechanical properties, *Constr. Build. Mater.* 240 (2020) 117978, <https://doi.org/10.1016/j.conbuildmat.2019.117978>.
- [12] I. Patra, G.R.L. Al-Awsi, Y.M. Hasan, S.S.K. Almotlaq, Mechanical properties of concrete containing recycled aggregate from construction waste, *Sustain. Energy Technol. Assessments* 53 (2022) 102722, <https://doi.org/10.1016/j.seta.2022.102722>.
- [13] *ASCE Standards, ANSI/ASCE 3-91: 1994 Standard for the structural design of composite slabs, American Society of Civil Engineers (1992).*
- [14] H. Zhang, Y. Geng, Y.-Y. Wang, Q. Wang, Long-term behavior of continuous composite slabs made with 100% fine and coarse recycled aggregate, *Eng. Struct.* 212 (2020) 110464, <https://doi.org/10.1016/j.engstruct.2020.110464>.

- [15] L.G.F. Grossi, C.F.R. Santos, M. Malite, Longitudinal shear strength prediction for steel-concrete composite slabs with additional reinforcement bars, *J. Constr. Steel Res.* 166 (2020) 105908, <https://doi.org/10.1016/j.jcsr.2019.105908>.
- [16] S. Chen, X. Shi, Shear bond mechanism of composite slabs — a universal FE approach, *J. Constr. Steel Res.* 67 (10) (2011) 1475–1484, <https://doi.org/10.1016/j.jcsr.2011.03.021>.
- [17] M.M. Rana, B. Uy, O. Mirza, Experimental and numerical study of the bond-slip relationship for post-tensioned composite slabs, *J. Constr. Steel Res.* 114 (2015) 362–379, <https://doi.org/10.1016/j.jcsr.2015.08.018>.
- [18] H. Zhang, Y. Geng, Y. Wang, X. Li, Experimental study and prediction model for bond behaviour of steel-recycled aggregate concrete composite slabs, *J. Build. Eng.* 53 (2022) 104585, <https://doi.org/10.1016/j.job.2022.104585>.
- [19] H. Mefteh, O. Kebaïli, H. Oucief, L. Berredjem, N. Arabi, Influence of moisture conditioning of recycled aggregates on the properties of fresh and hardened concrete, *J. Clean. Prod.* 54 (2013) 282–288, <https://doi.org/10.1016/j.jclepro.2013.05.009>.
- [20] F. Stochino, M. Zucca, M. Simoncelli, A. Alibeigibeni, G. Concu, M. Valdes, M.A. Pisani, C. Bernuzzi, M. Saccone, L. Pani, Experimental Investigation on the Structural Performance of Steel-Concrete Composite Slabs Incorporating Recycled Aggregates from Construction and Demolition Waste, *11th International Conference on Behaviour of Steel Structures in Seismic Areas*, 2024. STESSA 2024, Salerno.
- [21] L. Dadd, B. Bennett, T. Xie, P. Visintin, Shear behaviour and environmental impact of single and multi-generation recycled aggregate concrete beams, *Eng. Struct.* 322 (2025) 119200, <https://doi.org/10.1016/j.engstruct.2024.119200>.
- [22] M. Zaiter, H. El-Hassan, T. El-Maaddawy, Shear behavior of glass fiber-reinforced slag-fly ash blended geopolymer concrete beams, *Constr. Build. Mater.* 466 (2025) 140331, <https://doi.org/10.1016/j.conbuildmat.2025.140331>.
- [23] M. Karalar, B. Başaran, C. Aksoylu, Ö. Zeybek, E. Althaqafi, A.N. Beskopylny, S.A. Stel'makh, E.M. Shcherban', O.A. Umiye, Y.O. Özkılıç, Utilizing recycled glass powder in reinforced concrete beams: comparison of shear performance, *Sci. Rep.* 15 (2025) 6919, <https://doi.org/10.1038/s41598-025-91493-z>.
- [24] A. Santamaria, J.M. Romera, I. Marcos, V. Revilla-Cuesta, V. Ortega-López, Shear strength assessment of reinforced concrete components containing EAF steel slag aggregates, *J. Build. Eng.* 46 (2022) 103730, <https://doi.org/10.1016/j.job.2021.103730>.
- [25] T. Mustafa, M.O. El Hariri, M.A. Nader, W.M. Montaser, Enhanced shear behaviour of reinforced concrete beams containing Nano-Titanium, *Eng. Struct.* 257 (2022) 114082, <https://doi.org/10.1016/j.engstruct.2022.114082>.
- [26] J.W. Stark, Design of Composite Floors with Profiled Steel Sheet, *Fourth Speciality Conference on Cold-Formed Steel Structures*, 1978, pp. 893–922.
- [27] Eurocode 4, Design of Composite Steel and Concrete Structures. Part 1.1. General Rules and Rules for Buildings. EN 1994-1-1:2004, European Committee for Standardization, Brussels, 2004.
- [28] M.L. Porter e L.F. Greimann, Shear-bond Strength of Studded Steel Deck Slabs, *George Winter Memorial Conference, Seventh International Specialty Conference on Cold-Formed Steel Structures: Recent Research and Developments in Cold-Formed Steel*, Missouri-Rolla, 1984, pp. 285–306.
- [29] R. Johnson, N. Molenstra, Partial shear connection in composite beams for buildings, *Proc. Inst. Civ. Eng.* 91 (4) (1991) 679–704, <https://doi.org/10.1680/iicep.1991.17485>. , Ice Publishing.
- [30] D.J. Oehlers, e M.A. Bradford, *Composite Steel and Concrete Structural Members: Fundamental Behaviour*, PERGAMON, 1995.
- [31] J. Zhang, B. Zhong, D. Zhao, H. Dong, Bond-slip behavior between confined brick-concrete recycled aggregate concrete and reinforcement bars, *Constr. Build. Mater.* 436 (2024) 136919, <https://doi.org/10.1016/j.conbuildmat.2024.136919>.
- [32] C. Bai, J. Xue, Z. Luo, Experimental and finite element study on bond behavior between GFRP bar and recycled aggregate concrete, *Constr. Build. Mater.* 456 (2024) 139241, <https://doi.org/10.1016/j.conbuildmat.2024.139241>.
- [33] E. Kuoribo, H. Shokry, H. Mahmoud, Attaining material circularity in recycled construction waste to produce sustainable concrete blocks for residential building applications, *J. Build. Eng.* 96 (2024) 110503, <https://doi.org/10.1016/j.job.2024.110503>.
- [34] A.C. Tricco, et al., PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation, *Ann. Intern. Med.* 169 (7) (2018) 467–473, <https://doi.org/10.7326/M18-0850>.
- [35] M. Aria, C. Cuccurullo, Bibliometrix: an R-tool for comprehensive science mapping analysis, *J. Informetr.* 11 (4) (2017) 467–473, <https://doi.org/10.1016/j.joi.2017.08.007>.
- [36] A.M. Mineo, Una guida all "utilizzo dell' ambiente Statistico R, Dipartimento di Scienze Statistiche e Matematiche "S. Vianelli". Università degli studi di Palermo, 2003.
- [37] M. Cobo, A. López-Herrera, E. Herrera-Viedma, F. Herrera, SciMAT: a new science mapping analysis software tool, *J. Am. Soc. Inf. Sci. Technol.* 63 (8) (2012) 1609–1630, <https://doi.org/10.1002/asi.22688>.
- [38] B. Bicher, Concrete-Filled steel Tubes (CFT): innovative composite construction method facilitated by high-performance superplasticizer technology. *11th Annual International Fib Symposium on Concrete: 21st Century Superhero*, 2009. London.
- [39] Q. Yao, X. Yu, Y. Zhang, W. Huang, Mechanical characteristics and seismic performance of multi-rib slab wall, *J. Build. Struct.* 30 (SUPPL.2) (2009) 1–6.
- [40] J. Zhang, Y. Zhu, W. Cao, H. Dong, Flexural behavior of the recycled aggregate concrete composite slabs with closed-section steel deck, *J. Beijing Univ. Technol.* 40 (8) (2014) 1197–1203.
- [41] B. Coppola, L. Di Maio, L. Courard, P. Scarfato, L. Incarnato, Lightweight cementitious mortar made with foamed plastic waste aggregates, in: *1st International Workshop on Durability and Sustainability of Concrete Structures*, 2015. DSCS 2015, Bologna.
- [42] W. Li, J. Xiao, C. Shi, C.S. Poon, Structural behaviour of composite members with recycled aggregate concrete — an overview, *Adv. Struct. Eng.* 18 (6) (2015) 919–938, <https://doi.org/10.1260/1369-4332.18.6.919>.
- [43] J. Zhang, F. Liu, E. Kazoza, W. Cao, Experimental study on flexural behavior of recycled coarse aggregate concrete composite beams with closed-section steel deck, *J. Harbin Inst. Technol.* 47 (12) (2015) 86–92, <https://doi.org/10.11918/j.issn.0367-6234.2015.12.015>.
- [44] B. Wu, M.-M. Ji, X.-Y. Zhao, State-of-the-art of recycled mixed concrete (RMC) and composite structural members made of RMC, *Eng. Mech.* 33 (1) (2016) 1–10, <https://doi.org/10.6052/j.issn.1000-4750.2015.07.ST07>.
- [45] Y. Wang, Q. Wang, Y. Geng e G. Ranzi, Long-term behaviour of simply supported composite slabs with recycled coarse aggregate, *Mag. Concr. Res.* 68 (24) (2016), <https://doi.org/10.1680/jmacr.16.00090>.
- [46] A. Lapko, R. Grygo, Improving the structural behaviour RC precast concrete beams made of recycled aggregate concrete, *J. Civ. Eng. Manag.* 22 (2) (2016) 234–242, <https://doi.org/10.3846/13923730.2015.1023346>.
- [47] N. Mohamad, H. Khalifa, A.A. Abdul Samad, P. Mendis, W. Goh, Structural performance of recycled aggregate in CSP slab subjected to flexure load, *Constr. Build. Mater.* 115 (2016) 669–680, <https://doi.org/10.1016/j.conbuildmat.2016.04.086>.
- [48] P.R. Lopes Lima, A.B. Roque, C.M. Ariani Fontes, J.M. Feitosa Lima, J.A. Barros, Potentialities of cement-based recycled materials reinforced with sisal fibers as a filler component of precast concrete slabs, *Sustainable and Nonconventional Construction Materials using Inorganic Bonded Fiber Composites*, Holmer Savastano Junior, Juliano Fiorelli, and Sergio Francisco dos Santos (2017) 399–428, <https://doi.org/10.1016/B978-0-08-102001-2.00017-6>.
- [49] Y. Wang, Q. Wang, Y. Geng, State-of-the-Art of horizontal structural members using recycled aggregate concrete, *Eng. Mech.* 35 (4) (2018) 1–15, <https://doi.org/10.6052/j.issn.1000-4750.2017.06.ST10>.
- [50] K. Mikulica, R. Hela, Usage of recycled concrete as subsoil under industrial floor, *Key Eng Mater* (2018) 199–203, <https://doi.org/10.4028/www.scientific.net/KEM.760.199>.
- [51] P.R. Lima, J.A. Barros, A.B. Roque, C.M. Fontes, e J.M. Lima, Short sisal fiber reinforced recycled concrete block for one-way precast concrete slab, *Constr. Build. Mater.* 183 (2018) 620–634, <https://doi.org/10.1016/j.conbuildmat.2018.07.184>.
- [52] R. Chan, M.A. Santana, A.M. Oda, R.C. Paniguel, L.B. Vieira, A.D. Figueiredo e I. Galobardes, Analysis of potential use of fibre reinforced recycled aggregate concrete for sustainable pavements, *J. Clean. Prod.* 218 (2019) 183–191, <https://doi.org/10.1016/j.jclepro.2019.01.221>.
- [53] S. Deresa, H. Ren, J. Xu, Flexural behavior of glubam-recycled aggregate concrete composite beam. *3rd International Conference on Modern Bamboo Structures, ICBS 2018*, 2020, <https://doi.org/10.1201/9780429434990-17>. Beijing.
- [54] Q. Wang, Y. Yang, Y. Liang, H. Zhang, Y. Zhao, Q. Ren, Prediction of time-dependent behaviour of steel-recycled aggregate concrete (RAC) composite slabs via thermo-mechanical finite element modelling, *J. Build. Eng.* 29 (2020) 101191, <https://doi.org/10.1016/j.job.2020.101191>.

- [55] Q. Wang, Y. Liang, H. Zhang, Y. Zhan e Q. Ren, Time-dependent behavior of multi-span continuous steel-RCA composite slabs considering the loading distribution effects, *Eng. Mech.* 38 (2) (2021) 198–210, <https://doi.org/10.6052/j.issn.1000-4750.2020.04.0242>.
- [56] S. Tesfaye Deresa, J. Xu, B. Shan, H. Ren, Y. Xiao, Experimental investigation on flexural behavior of full-scale glued laminated bamboo (glubam)-concrete composite beams: a case study of using recycled concrete aggregates, *Eng. Struct.* 233 (2021) 111896, <https://doi.org/10.1016/j.engstruct.2021.111896>.
- [57] A.B. Awan, F.U.A. Shaikh, Structural behavior of recycled tire crumb rubber sandwich panel in flexural bending, *Struct. Concr.* 22 (6) (2021) 3602–3619, <https://doi.org/10.1002/suco.202100356>.
- [58] H. Zhang, Y. Wang, Q. Wang, Y. Geng, Experimental study and prediction model for non-uniform shrinkage of recycled aggregate concrete in composite slabs, *Constr. Build. Mater.* 329 (2022) 127142, <https://doi.org/10.1016/j.conbuildmat.2022.127142>.
- [59] J. Yang, C. Liu, Q. Wang, Y. Geng, Time-dependent behavior of composite steel–recycled aggregate concrete beams via thermomechanical finite element modeling, *Buildings* 12 (6) (2022) 756, <https://doi.org/10.3390/buildings12060756>.
- [60] H. Zhao, J. Zhao, R. Wang, W. Zhang, F. Liu, S. Wu, Thermal behavior of composite slabs with closed profiled steel decking and recycled aggregate concrete in fire, *Fire Saf. J.* 132 (2022) 103637, <https://doi.org/10.1016/j.firesaf.2022.103637>.
- [61] H. Zhang, Y. Geng, Q. Wang, Y. Wang, Compounding effect between influences of fine and coarse recycled aggregates on non-uniform shrinkage behavior of steel-concrete composite slab section, *J. Build. Eng.* 56 (2022) 104751, <https://doi.org/10.1016/j.jobe.2022.104751>.
- [62] L. Lu, M. Gao, Y. Guo, W. Wang, H. Yan, T. Jiang, Experiments on flexural behavior of the prefabricated RAC and NWC composite slab, *Ain Shams Eng. J.* 13 (6) (2022), <https://doi.org/10.1016/j.asej.2022.101789>.
- [63] H. Zhang, H. Zhang, Y. Geng, P. Fang, Y. Wang, Design formulae for Long-Term responses of continuous Steel-Recycled aggregate concrete composite slabs, *Structures* 45 (2022) 1477–1490, <https://doi.org/10.1016/j.istruc.2022.09.092>.
- [64] E. Liu, M. Lin, Q. Xie, Y. Zhang, Flexural performance of prestressed composite recycled aggregate slabs with steel tube trusses, *KSCSE J. Civ. Eng.* 26 (12) (2022) 5253–5263, <https://doi.org/10.1007/s12205-022-0563-x>.
- [65] L. Lu, W. Wang, L. Zhang, Y. Shao, Longitudinal shear strength of recycled aggregate concrete prefabricated superimposed slabs, *Eng. Struct.* 281 (2023) 115745, <https://doi.org/10.1016/j.engstruct.2023.115745>.
- [66] J. Dong, Y. Liu, S. Yuan, Q. Wang, Z. Wei, Study on fatigue performance of basalt fiber reinforced recycled concrete web box girder, *J. Build. Struct.* 44 (2023) 174–182, <https://doi.org/10.14006/j.jzjgxb.2023.S1.0020>.
- [67] B. Chen, T. Zhang, Y. Geng, Q. Wang, G. Zhao, J. Yang, Longitudinal shear tests and design methods for corrugated steel–concrete composite slabs with recycled coarse aggregate, *Constr. Build. Mater.* 400 (2023) 132870, <https://doi.org/10.1016/j.conbuildmat.2023.132870>.
- [68] R. Zhang, J. Jiao, M. He, Z. Tao, P. He, Design, implementation and performance prediction of profiled steel sheet-mixed aggregate recycled concrete hollow composite slab, *J. Build. Eng.* 79 (2023) 107839, <https://doi.org/10.1016/j.jobe.2023.107839>.
- [69] S. Fareed, A. Khan, Behavior of reinforced recycled aggregate concrete beams and slabs strengthened in flexure and punching with CFRP composites, *J. Textile Inst.* 115 (11) (2024) 2116–2124, <https://doi.org/10.1080/00405000.2023.2281020>.
- [70] B. Athuya, M.M. Jacob, Numerical investigation on shear bond improvement of high-performance concrete composite slabs containing recycled aggregates. *4th International Conference on Structural Engineering and Construction Management, SECON 2023*, Angamaly, 2024.
- [71] S. Niranjana, M.M. Jacob, Numerical analysis on flexural strength of composite slab with inverted U-shaped shear connector. *4th International Conference on Structural Engineering and Construction Management, SECON 2023*, Angamaly, 2024.
- [72] F. Kefyalew, T. Imjai, R. Garcia, N. Khanh Son, S. Chaudhary, Performance of recycled aggregate concrete composite metal decks under elevated temperatures: a comprehensive review, *J. Asian Architect. Build. Eng.* (2024) 1–23, <https://doi.org/10.1080/13467581.2024.2309347>.
- [73] F. Kefyalew, T. Imjai, R. Garcia, B. Kim, Structural and service performance of composite slabs with high recycled aggregate concrete contents, *Eng Sci* 27 (2023) 1021, <https://doi.org/10.30919/es1021>.
- [74] H. Zhao, J. Wang, J. Zhao, F. Liu, R. Wang, Fire performance of recycled aggregate concrete composite slabs with closed profiled steel decking, *J. Build. Struct.* 52 (2) (2024) 74–81, <https://doi.org/10.14006/j.jzjgxb.2022.0854>.
- [75] H.H. Elgaali, M. Lopez-Arias, M. Velay-Lizancos, Accelerated CO₂ exposure treatment to enhance bio-receptivity properties of mortars with natural and recycled concrete aggregate, *Constr. Build. Mater.* 449 (2024) 138423, <https://doi.org/10.1016/j.conbuildmat.2024.138423>.
- [76] F. Kefyalew, T. Imjai, R. Garcia, N.K. Son, Fire behavior of high-contents recycled aggregate concrete composite slabs with small openings, *Struct. Concr.* 25 (6) (2024) 4498–4514, <https://doi.org/10.1002/suco.202400242>.
- [77] F. Stochino, A. Alibeigibeni, M. Zucca, M. Valdes, G. Concu, M. Simoncelli, M.A. Pisani, C. Bernuzzi, Mechanical behavior of composite slabs with recycled concrete aggregates: a preliminary study, *Structures* 70 (2024) 107838, <https://doi.org/10.1016/j.istruc.2024.107838>.
- [78] R.V. Gibbin, T.F. Sigahi, J.D.S. Pinto, I.S. Rampasso, R. Anholon, Thematic evolution and trends linking sustainability and project management: scientific mapping using SciMAT, *J. Clean. Prod.* 414 (2023) 137753, <https://doi.org/10.1016/j.jclepro.2023.137753>.
- [79] S.M. Ahmed, S. Avudaiappan, I.S. Sheet, E.I. Saavedra Flores, J.C. Pina, S.J. Yanez, C.F. Guzmán, Prediction of longitudinal shear resistance of steel-concrete composite slabs, *Eng. Struct.* 193 (2019) 295–300, <https://doi.org/10.1016/j.engstruct.2019.05.010>.
- [80] M. Saravanan, V. Marimuthu, P. Prabha, S. Arul Jayachandran, D. Datta, Experimental investigations on composite slabs to evaluate longitudinal shear strength, *Steel Compos. Struct.* 13 (5) (2012) 489–500, <https://doi.org/10.12989/SCS.2012.13.5.489>.
- [81] H. Wright, H. Evans, P. Harding, The use of profiled steel sheeting in floor construction, *J. Constr. Steel Res.* 7 (4) (1987) 279–295, [https://doi.org/10.1016/0143-974X\(87\)90003-4](https://doi.org/10.1016/0143-974X(87)90003-4).
- [82] P. Mäkeläinen, Y. Sun, The longitudinal shear behaviour of a new steel sheeting profile for composite floor slabs, *J. Constr. Steel Res.* 49 (2) (1999) 117–128, [https://doi.org/10.1016/S0143-974X\(98\)00211-9](https://doi.org/10.1016/S0143-974X(98)00211-9).
- [83] M.J. Burnet, D.J. Oehlers, Rib shear connectors in composite profiled slabs, *J. Constr. Steel Res.* 57 (12) (2001) 1267–1287, [https://doi.org/10.1016/S0143-974X\(01\)00038-4](https://doi.org/10.1016/S0143-974X(01)00038-4).
- [84] X. Li, X. Zheng, M. Ashraf, H. Li, Experimental study on the longitudinal shear bond behavior of lightweight aggregate concrete – closed profiled steel sheeting composite slabs, *Constr. Build. Mater.* 156 (2017) 599–610, <https://doi.org/10.1016/j.conbuildmat.2017.08.108>.
- [85] K. Poh, M. Attard, Calculating the load-deflection behaviour of simply-supported composite slabs with interface slip, *Eng. Struct.* 15 (5) (1993) 359–367, [https://doi.org/10.1016/0141-0296\(93\)90039-7](https://doi.org/10.1016/0141-0296(93)90039-7).
- [86] M. Crisinel, F. Marimon, A new simplified method for the design of composite slabs, *J. Constr. Steel Res.* 60 (3–5) (2004) 481–491, [https://doi.org/10.1016/S0143-974X\(03\)00125-1](https://doi.org/10.1016/S0143-974X(03)00125-1).
- [87] O. Yi, Y. Zhuge, X. Ma, R.J. Gravina, J.E. Mills, O. Youssf, Push-off and pull-out bond behaviour of CRC composite slabs – an experimental investigation, *Eng. Struct.* 228 (2021) 111480, <https://doi.org/10.1016/j.engstruct.2020.111480>.
- [88] L. Butler, J.S. West, S.L. Tighe, The effect of recycled concrete aggregate properties on the bond strength between RCA concrete and steel reinforcement, *Cement Concr. Res.* 41 (10) (2011) 1037–1049, <https://doi.org/10.1016/j.cemconres.2011.06.004>.
- [89] M.L. Porter, C.E. Ekberg, Design recommendations for steel deck floor slabs, *J. Struct. Div.* 102 (11) (1976) 2121–2136, <https://doi.org/10.1061/JSDIAG.0000474>.
- [90] C. Bernuzzi, M.A. Pisani, M. Simoncelli, Debonding strain for steel-concrete composite slabs with trapezoidal metal deck, *Steel Compos. Struct.* 49 (1) (2023) 19–30, <https://doi.org/10.12989/SCS.2023.49.1.019>.
- [91] A. Gholamhoseini, R. Gilbert, M. Bradford, Z. Chang, Longitudinal shear stress and bond-slip relationships in composite concrete slabs, *Eng. Struct.* 69 (2014) 37–48, <https://doi.org/10.1016/j.engstruct.2014.03.008>.
- [92] A. Redzuan, W. Samuel Easterling, New evaluation and modeling procedure for horizontal shear bond in composite slabs, *J. Constr. Steel Res.* 65 (4) (2009) 891–899, <https://doi.org/10.1016/j.jcsr.2008.10.009>.
- [93] L. Lu, Y. Ding, Y. Guo, H. Hao, S. Ding, Flexural performance and design method of the prefabricated RAC composite slab, *Structures* 38 (2022) 572–584, <https://doi.org/10.1016/j.istruc.2022.02.022>.
- [94] F. Fritsch, R. Carlson, Monotone piecewise cubic interpolation, *SIAM J. Numer. Anal.* 17 (2) (1980), <https://doi.org/10.1137/0717021>.

- [95] JGJ 138-2016, Code for Design of Composite Structure, China Architecture and Building Press, Beijing, 2016. China.
- [96] J. Xiao, W. Li, Y. Fan, X. Huang, An overview of study on recycled aggregate concrete in China (1996–2011), *Constr. Build. Mater.* 31 (2012) 364–383, <https://doi.org/10.1016/j.conbuildmat.2011.12.074>.
- [97] J. Nie, L. Tang, L. Huang, Load-carrying and deforming capacities of composite slabs with re-entrant trough profiled steel sheeting (I): experiment and longitudinal shear capacity, *Build Struct* 1 (1) (2007) 60–64.
- [98] W.-Q. Lyu, L.-H. Han, Investigation on bond strength between recycled aggregate concrete (RAC) and steel tube in RAC-filled steel tubes, *J. Constr. Steel Res.* 155 (2019) 438–459, <https://doi.org/10.1016/j.jcsr.2018.12.028>.
- [99] A. Yacoub, A. Djerbi, T. Fen-Chong, Water absorption in recycled sand: new experimental methods to estimate the water saturation degree and kinetic filling during mortar mixing, *Constr. Build. Mater.* 158 (2018) 464–471, <https://doi.org/10.1016/j.conbuildmat.2017.10.023>.
- [100] A.A. Shirgaonkar, Y.D. Patil, H.S. Patil, Influence of stiffeners and pattern of shear screws on behaviour of cold formed profiled deck composite floor, *Case Stud. Constr. Mater.* 15 (2021) e00572, <https://doi.org/10.1016/j.cscm.2021.e00572>.
- [101] Eurocode 2, Design of Concrete Structures. Part 1.1. General Rules and Rules for Buildings. EN 1992-1-1:2004, European Committee for Standardization, Brussels, 2004.