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Advancing Sustainability and Performance: A Review on Recycled Aggregates and Portland Slag Cement in Construction

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Abstract- The construction industry faces increasing pressure to adopt sustainable practices due to resource depletion and waste management challenges. This review critically examines the use of Portland Slag Cement (PSC) in combination with Recycled Aggregate Concrete (RAC) to enhance sustainability and performance in construction. The analysis consolidates research on the mechanical properties, durability, and environmental impact of PSC-RAC composites. Findings show that PSC enhances compressive strength, tensile strength, and long-term durability while reducing the carbon footprint of concrete production. The review highlights the superior performance of PSC in comparison to traditional cementitious materials, particularly in harsh environments. However, challenges remain regarding the variability in the quality of recycled aggregates, workability issues, and economic feasibility. This review emphasizes the need for standardized quality controls for recycled materials and advocates for further research into long-term performance and the integration of PSC with advanced materials such as Nano-Silica. Comprehensive studies and cost-benefit analyses are recommended to fully explore the feasibility of PSC-RAC in both structural and non-structural applications.

Index Terms- Sustainable Construction Materials – Environmental Impact - Durability of Concrete – Recycled Aggregate Concrete

I. INTRODUCTION

The construction sector, a cornerstone of global economic growth, is increasingly under scrutiny due to its significant environmental impact. Resource depletion, carbon emissions, and waste management issues have driven the industry to explore more sustainable materials and methods. Among the most promising alternatives is Recycled Aggregate Concrete (RAC), which uses aggregates sourced from demolished structures to reduce the demand for virgin materials. RAC offers the potential to lower landfill use, conserve natural resources, and minimize the environmental footprint associated with aggregate extraction and processing [1].

However, the adoption of RAC in construction has been hampered by concerns over its mechanical properties and durability, particularly in comparison to traditional concrete. The variability in the quality of recycled aggregates introduces inconsistencies in the strength and performance of RAC, limiting its use in structural applications [2].

The incorporation of Portland Slag Cement (PSC), a by-product of iron and steel manufacturing, offers a potential solution to the environmental and structural challenges in RAC. PSC enhances the compressive and tensile strengths of RAC while improving its resistance to environmental degradation, such as chemical attacks and freeze-thaw cycles. By reducing permeability, PSC also enhances durability, particularly against sulfate and chloride penetration, which are critical for the longevity of concrete structures [3], [4]. The slag in PSC reacts with other components to form additional cementitious materials, further strengthening the concrete. Moreover, PSC contributes to sustainability by lowering carbon emissions compared to OPC by repurposing industrial waste and reducing energy requirements during production. These factors are crucial in promoting sustainable construction practices and align with global efforts to reduce greenhouse gas emissions [5].

2. Objectives

This review aims to evaluate the potential of Portland slag cement (PSC) in enhancing the performance of recycled aggregate concrete (RAC) and to assess its role in promoting sustainability in construction. This review will analyze the mechanical properties of RAC-PSC composites, such as compressive strength, tensile strength, and modulus of elasticity. It will also examine durability factors, including permeability, freeze-thaw, and chemical resistance, alongside

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the environmental benefits assessed through life cycle analysis and sustainability indices. By synthesizing existing research, this review aims to provide insights that could guide future research and practical applications, contributing to more sustainable construction practices.

II. LITERATURE REVIEW

1. Historical Development of RAC and PSC Integration

Recycled Aggregate Concrete (RAC) has evolved from its early use in non-structural applications to being considered for more demanding roles in structural engineering. Early concerns over the reduced strength and durability of RAC, particularly when used in conjunction with traditional cementitious materials, limited its widespread adoption. However, the development of supplementary cementitious materials, such as Portland Slag Cement (PSC), has expanded the potential of RAC, allowing it to meet and even exceed the performance of conventional concrete in certain applications [6], [7].

Xu et al. [8] demonstrated that PSC's pozzolanic properties significantly improve the compressive strength and durability of RAC by enhancing the microstructure of the concrete matrix. These improvements are particularly pronounced in environments exposed to aggressive chemical agents, such as sulfate and chloride ions. Research by Majhi and Nayak [9] corroborates these findings, showing that PSC reduces the permeability of RAC, thus increasing its resistance to chloride ion penetration and subsequent reinforcement corrosion.

Despite these advancements, integrating PSC with RAC has not been without challenges. The variability in recycled aggregates, stemming from the diverse sources and conditions of the original concrete, remains a significant concern. Studies have consistently highlighted the need for standardized quality controls to ensure the consistent performance of RAC, particularly in structural applications. Voit et al. [10] emphasized the importance of advanced processing technologies, such as improved crushing and screening methods, to mitigate the variability in RCA quality.

2. Mechanical Properties and Durability Aspects

The mechanical properties of RAC, when combined with PSC, have been extensively studied, showing promising results. Although RAC might initially exhibit lower strength than conventional concrete, studies demonstrate that the inclusion of PSC can result in comparable or even superior long-term strength. The ongoing pozzolanic reactions in PSC contribute to a denser and more durable microstructure [11]. For example, research indicates that RAC with PSC achieves significant compressive strength improvements, particularly after 28 days of curing, compared to concrete made with OPC [12]. Moreover, the inclusion of PSC mitigates some of the drawbacks of recycled aggregates, such as increased shrinkage and reduced stiffness, enhancing the structural viability of RAC [13], [14], [15].

A study found that the compressive strength of concrete decreases with an increasing percentage of RCA. However, the reduction is more pronounced in OPC-based mixes than in PSC-based mixes. For example, a 100% RCA mix with PSC showed a decrease of 19.1% in compressive strength compared to a 0% RCA mix, while the same reduction for OPC was 10.7%. This suggests that PSC may mitigate some of the strength losses associated with RCA. In contrast, split tensile strength continuously decreased with the addition of RCA. Interestingly, the reduction was less severe in PSC-based mixes, indicating PSC's potential to enhance the tensile strength of RCA concrete. Although the study does not delve deeply into the long-term durability aspects, the initial results suggest that PSC-based RCA concrete may offer better durability, particularly in terms of resistance to chemical attacks and freeze-thaw cycles [16].

Another study offered significant insights into the potential of using industrial by-products and recycled materials in concrete production by substituting portions of OPC, sand, and granite with cupola furnace slag (CFS) and RCA. The inclusion of CFS as a partial replacement for OPC improves the compressive strength of the concrete at specific replacement levels. For instance, a 10% replacement of OPC with CFS resulted in a notable increase in compressive strength at both 28 and 56 days, indicating the potential of CFS to enhance concrete strength. Similarly, the partial replacement of sand with fine CFS (FCFS) led to improved strength at replacement levels up to 30%. However, the study also found that further increases in the replacement levels of both cement and aggregates led to a decrease in compressive strength, particularly when CFS was used as a coarse aggregate.

The microstructural analysis using scanning electron microscopy (SEM) revealed that the incorporation of CFS reduces the porosity of the concrete, which is likely responsible for the observed improvements in compressive strength. The formation of additional calcium silicate hydrate (C-S-H) gel, a key contributor to concrete strength, was noted in mixes with CFS, supporting the material's role in enhancing concrete properties.

Despite these promising findings, the study also highlights some limitations of using CFS and RCA in concrete. The workability of the concrete decreases as the percentage of CFS and RCA increases, likely due to the higher water absorption and rough surface texture of these materials. Additionally, while partial replacements yielded positive results, the complete replacement of sand and granite with CFS and RCA significantly reduced compressive strength,

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indicating that these materials may not fully substitute traditional aggregates in structural applications [6].

A further investigation examines the effects of replacing traditional concrete materials with alternative and recycled materials. Specifically, the study examines the partial replacement of OPC with Ground Granulated Blast Furnace Slag (GGBS), the complete replacement of natural fine aggregate (NFA) with Granulated Blast Furnace Slag (GBS), and the partial to complete replacement of NCA with RCA. The research focuses on understanding how these replacements affect the compressive strength and split tensile strength of M30-grade concrete. The study significantly contributes to the ongoing efforts to produce more sustainable concrete by reducing the reliance on natural resources and incorporating industrial by-products and recycled materials. The key findings suggest that replacing NFA with GBS and partially replacing OPC with GGBS can improve the compressive and tensile strengths of concrete. Specifically, the study shows that a 100% replacement of NFA with GBS and a 30% replacement of OPC with GGBS result in higher strength than conventional concrete, particularly at the 7, 14, and 28-day marks. However, introducing RCA as a replacement for NCA reduces both compressive and tensile strengths, particularly as the proportion of RCA increases. Despite this, the study identifies an optimal replacement level of 80% RCA, beyond which the strength properties decline significantly. This suggests that while RCA can be used effectively in concrete, its proportion needs to be carefully controlled to maintain the desired strength characteristics.

The study also highlights the challenge of workability when using these alternative materials. The use of RCA leads to reduced workability due to its higher water absorption capacity. Superplasticizers could mitigate this issue, although the study did not explore this in depth[17].

An experimental study examines the durability of concrete made with high volumes of RCA and PSC incorporated with Nano-Silica (NS). The study focuses on the effects of replacing NCA with RCA at various percentages (30%, 45%, and 60%) and OPC with PSC while incorporating PSC with (NS) to enhance the durability and strength properties of the concrete. The study highlights the effect of those replacements on the durability properties. It was found that at 45% RCA replacement, the concrete demonstrated optimal performance in terms of both strength and durability. However, at 60% replacement, the strength and durability properties began to decline, indicating a threshold beyond which the benefits of using RCA diminish. The research also explores the impact of RCA with NS and PSC on water absorption and permeability, finding that while water absorption increases with higher RCA content, the use of PSC and NS helps to mitigate this effect by reducing the permeability of the concrete.

Resistance to acid attack was another critical aspect evaluated in the study. The results showed that concrete with 45% RCA replacement and PSC with NS exhibited better acid attack resistance than conventional concrete. The durability index, measured as the Acid Durability Loss Factor (ADLF), was lower for concrete with RCA and PSC. Further investigations are needed to examine the potential of these materials to produce durable concrete for challenging environments, such as coastal or industrial areas [18].

While durability is a critical factor in the long-term performance of RAC, particularly in harsh environments, the incorporation of PSC has been shown to significantly enhance the durability of RAC, making it more resistant to chemical attacks, such as chloride and sulfate exposure. Sujatha and Murty [19] found that PSC reduces water absorption and permeability in RAC, making it more suitable for use in coastal and industrial environments where concrete is exposed to aggressive chemicals.

3. Environmental Impact and Sustainability
The environmental benefits of using PSC in RAC are substantial. Life cycle assessments conducted by Younis et al. [20] and Abushanab et al. [21] demonstrated that PSC reduces the carbon footprint of concrete production by up to 30% compared to traditional cement. PSC also promotes the recycling of industrial by-products, such as slag, which further reduces the demand for virgin materials and minimizes waste generation [22], [23]. These findings are supported by studies that highlighted the role of PSC in reducing both the environmental and economic costs associated with concrete production [24]

Despite these advantages, there are still challenges to the widespread adoption of PSC-RAC composites. The variability in recycled aggregates, as noted in multiple studies, can affect the long-term durability of RAC, particularly in structural applications where high performance is critical. Additionally, the use of PSC can result in reduced workability. This issue may require chemical admixtures, such as superplasticizers, to ensure proper mix consistency and ease of placement [13].

III. RESULTS AND DISCUSSION

1. Mechanical Performance of RAC with PSC

The integration of PSC with RAC significantly improves the compressive and tensile strengths of the composite material. The results of this review show that PSC enhances the mechanical properties of RAC by densifying the concrete matrix and improving the bond between recycled aggregates and the cement paste. Studies demonstrated that using PSC in RAC resulted in compressive strengths that exceeded those of conventional concrete after 28 days of curing. This improvement is largely due to the pozzolanic activity of slag, which contributes to the formation of additional calcium

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silicate hydrate (C-S-H) gels, thereby increasing the overall strength and durability of the concrete [12].

In terms of tensile strength, PSC mitigates the typical reductions observed in RAC, as evidenced by many studies [25]. The study found that the inclusion of PSC reduced the severity of strength loss, making RAC with PSC a viable option for structural applications. However, the mechanical performance of RAC with PSC is influenced by several factors, including the quality of the recycled aggregates and the mix design. Variability in the source and condition of the recycled aggregates can lead to inconsistencies in the strength of RAC [13]. To address this issue, further research is needed to standardize the processing and grading of recycled aggregates [10], [26], [27].

2. Durability and Long-Term Performance

The durability of RAC with PSC is a critical factor in its application for structural and non-structural purposes. PSC has been shown to significantly enhance the durability of RAC, particularly in environments exposed to aggressive chemicals. Sujatha and Murty [18], [19] demonstrated that the use of PSC reduces permeability and increases resistance to chloride and sulfate attacks, making it suitable for use in marine environments and areas with high sulfate content.

The review also highlights the importance of addressing long-term performance issues associated with RAC, particularly in terms of shrinkage and cracking. Studies observed that RAC tends to exhibit higher drying shrinkage and lower abrasion resistance compared to conventional concrete. While PSC can mitigate some of these issues by reducing permeability and improving the concrete matrix, further research is needed to explore the long-term behavior of RAC with PSC under varying environmental conditions [13].

IV. LIMITATIONS AND CHALLENGES IN EXISTING STUDIES

While the body of research on RAC and PSC presents promising advancements, several limitations and challenges within these studies must be addressed to improve their applicability and reliability. A critical evaluation of each study reveals areas that require further investigation, particularly concerning the variability in material quality, economic feasibility, environmental impact, and market acceptance.

1. Material Quality and Performance Consistency

One of the most common limitations identified across the reviewed studies is the significant variability in the quality of recycled aggregates. This variability arises from differences in the source of recycled aggregates, the composition of the original concrete, and the processing methods employed. Such inconsistencies can adversely affect the performance of RAC, leading to unpredictability in compressive strength, durability, and other mechanical properties [7]. Despite many studies acknowledging this issue, few provide robust solutions or standardized methods to mitigate these inconsistencies. Without consistent quality controls, the application of RAC with PSC in structural concrete remains uncertain, limiting its broader use in critical load-bearing structures.

Additionally, most studies tend to focus on short-term mechanical properties like compressive strength and flexural strength, with limited data on long-term durability and performance under varying environmental conditions. The absence of long-term studies makes it difficult to predict how RAC with PSC will perform over decades, particularly in aggressive environments such as coastal areas or industrial zones where chemical exposure is a concern [7], [28].

2. Economic Challenges

The economic challenges associated with the use of PSC and high-quality recycled aggregates are multifaceted. One of the primary issues is the higher initial cost related to the collection, sorting, and processing of recycled aggregates to ensure they meet construction-grade quality standards. The availability of high-quality recycled materials and PSC can also vary significantly by region, which affects the cost and practicality of using these materials [29]. In areas where industrial by-products like slag are scarce, the need to transport or import these materials can significantly increase project costs, thus limiting their adoption in mainstream construction.

Moreover, market acceptance remains a significant barrier. Despite the clear environmental and technical benefits of using recycled aggregates and PSC, skepticism about their performance and long-term reliability persists. Building trust in recycled materials among stakeholders, including construction companies, architects, and end-users, is essential for their wider adoption. This would require ongoing education, demonstration projects, and real-world applications to showcase the benefits of these materials [30].

3. Environmental Challenges

While PSC and recycled aggregates offer substantial environmental benefits, their use is not without challenges. The processing of recycled aggregates involves energy-intensive operations, such as crushing and sorting, which must be managed carefully to avoid offsetting the environmental gains associated with recycling [7]. Additionally, the transportation of these materials, particularly over long distances, can result in increased fuel consumption and greenhouse gas emissions. This transportation burden can undermine the overall sustainability benefits of using recycled materials, especially when the distance between the source of recycled aggregates and the construction site is considerable [31].

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Despite these challenges, the environmental advantages of PSC and recycled aggregates remain substantial. The use of PSC, which incorporates slag from steel manufacturing, reduces industrial waste and lowers the reliance on clinker, a major source of CO2 emissions in cement production [32]. Furthermore, life cycle assessments have demonstrated that using PSC and recycled aggregates in concrete can reduce the total environmental impact of construction projects, making them a valuable component of sustainable building practices [20].

4. Application in Structural vs. Non-Structural Projects

Most of the reviewed studies focus on non-structural applications of RAC and PSC, such as pavements, walkways, and non-load-bearing walls. While these findings are valuable, they may not be directly applicable to structural applications, where higher performance standards—such as load-bearing capacity, long-term durability, and resilience to environmental stressors—are required [31]. The lack of data on RAC and PSC in structural applications limits the potential for these materials to be fully integrated into mainstream construction projects, especially for critical infrastructure such as bridges and high-rise buildings [33], [34].

V. CONCLUSION

The integration of Portland slag cement (PSC) with recycled aggregate concrete (RAC) presents a robust solution to some of the most pressing challenges in sustainable construction. This review, alongside the original research findings, demonstrates that RAC with PSC not only meets but often surpasses the performance standards of conventional concrete. The combination of PSC with recycled aggregates offers significant benefits in terms of mechanical properties, durability, and environmental impact.

The mechanical properties of RAC, particularly compressive and flexural strengths, are significantly enhanced by the addition of PSC. Studies confirm that PSC helps to mitigate the typical strength reductions associated with recycled aggregates, resulting in a concrete mix that is not only structurally sound but also capable of withstanding environmental stressors [12], [25].

Durability is another critical area in which RAC with PSC excels. The enhanced resistance to chloride penetration, sulfate attack, and other forms of chemical degradation makes RAC with PSC particularly suitable for use in aggressive environments, such as coastal and industrial areas. The findings from [13], [17], [18] further reinforce the idea that PSC significantly improves the long-term performance of RAC.

From an environmental perspective, the use of PSC in RAC contributes to significant reductions in carbon emissions and resource consumption. By utilizing industrial by-products like slag and repurposing construction and demolition waste, RAC with PSC offers a more sustainable alternative to traditional concrete. Life cycle assessments, as discussed in studies like [12], highlight the potential of RAC with PSC to lower the overall environmental footprint of construction projects by up to 30%.

Using advanced materials like Nano-Silica to enhance the durability properties of RAC when combined with PSC was found to improve the concrete's microstructure by filling micro-pores, reducing porosity, and thereby increasing the concrete's resistance to environmental stressors such as chemical attacks and permeability issues [18].

Conflict of Interest

The authors declare that they have no financial interests related to the contents of this article.

REFERENCES

1. S. Sakir, S. N. Raman, M. Safiuddin, A. B. M. Amrul Kaish, and A. A. Mutalib, "Utilization of by-products and wastes as supplementary cementitious materials in structural mortar for sustainable construction," Sustainability (Switzerland), vol. 12, no. 9, p. 3888, 2020, doi: 10.3390/su12093888.
2. R. V Silva, J. De Brito, and R. K. Dhir, "Performance of cementitious renderings and masonry mortars containing recycled aggregates from construction and demolition wastes," Constr Build Mater, vol. 105, pp. 400–415, 2016.
3. K. McNeil and T. H. K. Kang, "Recycled Concrete Aggregates: A Review," Mar. 01, 2013, Korea Concrete Institute. doi: 10.1007/s40069-013-0032-5.
4. M. El-Hawary, A. Al-Yaqout, and K. Nouh, "Durability of recycled aggregate concrete incorporating slag," Proceedings of Institution of Civil Engineers: Waste and Resource Management, vol. 172, no. 4, pp. 107–117, Nov. 2019, doi: 10.1680/jwarm.18.00025.
5. C. Pellegrino and F. Faleschini, Sustainability improvements in the concrete industry: use of recycled materials for structural concrete production. Springer, 2016. [Online]. Available: https://link.springer.com/book/10.1007/978-3-319-28540-5
6. A. J. Adese, O. D. Olajide, and O. A. Olayenikan, "Properties of Concrete Made from Cupola Furnace Slag and Recycled Construction Aggregates," European Journal of Engineering and Technology Research, vol. 6, no. 7, pp. 52–61, Nov. 2021, doi: https://dx.doi.org/10.24018/ejers.2021.6.7.2642.
7. B. Wang, L. Yan, Q. Fu, and B. Kasal, "A Comprehensive Review on Recycled Aggregate and Recycled Aggregate

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Concrete," Resour Conserv Recycl, vol. 171, p. 105565, Aug. 2021, doi: 10.1016/J.RESCONREC.2021.105565.
8. L. Xu et al., "Modification of recycled cement with phosphogypsum and ground granulated blast furnace slag," 2024. doi: 10.1016/j.conbuildmat.2024.136241.
9. R. K. Majhi, A. N. Nayak, and B. B. Mukharjee, "Development of sustainable concrete using recycled coarse aggregate and ground granulated blast furnace slag," Constr Build Mater, vol. 159, pp. 417–430, 2018, doi: 10.1016/j.conbuildmat.2017.10.118.
10. K. Voit, O. Zeman, I. Janotka, R. Adamcova, and K. Bergmeister, "High-durability concrete using eco-friendly slag-pozzolanic cements and recycled aggregate," Applied Sciences, vol. 10, no. 22, p. 8307, 2020, doi: 10.3390/app10228307.
11. R. K. Majhi and A. N. Nayak, "Bond, durability and microstructural characteristics of ground granulated blast furnace slag based recycled aggregate concrete," Constr Build Mater, vol. 212, pp. 578–595, 2019, doi: 0.1016/j.conbuildmat.2019.04.017.
12. Kundan Kumar Singh and Prabhu Nath Singh, "Mechanical behavior of concrete containing recycled aggregates," International Journal of Science and Research Archive, vol. 8, no. 1, pp. 1030–1038, Feb. 2023, doi: 10.30574/ijsra.2023.8.1.0129.
13. KK Sagoe Crentsil, T Brown, and AH Taylor, "Durability And Performance Characteristics Of Recycled Aggregate Concrete," in 9th International Conference on Durability of Building Materials and Components (9DBMC), Brisbane, Australia, 17-21 March 2002, CSIRO, 2002. doi: https://www.irbnet.de/daten/iconda/CIB9930.pdf.
14. K. Shicong, "Reusing recycled aggregates in structural concrete." [Online]. Available: https://www.researchgate.net/publication/47870593
15. M. Noël, L. Sanchez, and G. Fathifazl, "Recent advances in sustainable concrete for structural applications," in Sustainable Construction Materials and Technologies, International Committee of the SCMT conferences, 2016. doi: 10.18552/2016/scmt4s210.
16. P. P. S et al., "A STUDY ON RECYCLED CONCRETE AGGREGATES." [Online]. Available: http://www.ijpam.eu
17. N. P. S and L. Reddy, "Properties of Concrete with GBS and RCA," ijasre, vol. 3, no. 1, pp. 309–315, Aug. 2017, [Online]. Available: www.ijasre.net
18. T. Sujatha and D. S. R. Murty, "Experimental Investigation on Durability Study of Portland Slag Concrete with Influence of High-Volume Recycled Aggregate," Civil Engineering and Architecture, vol. 11, no. 3, pp. 1576–1588, May 2023, doi: 10.13189/cea.2023.110337.
19. T. Sujatha and D. S. R. Murty, "Performance of slag based recycled coarse aggregate concrete with steel fibers," Mater Today Proc, Aug. 2023, doi: 10.1016/J.MATPR.2023.08.063.
20. A. Younis, U. Ebead, and S. Judd, "Life cycle cost analysis of structural concrete using seawater, recycled concrete aggregate, and GFRP reinforcement," Constr Build Mater, vol. 175, pp. 152–160, Jun. 2018, doi: 10.1016/j.conbuildmat.2018.04.183.
21. A. Abushanab and W. Alnahhal, "Performance of sustainable concrete incorporating treated domestic wastewater, RCA, and fly ash," Constr Build Mater, vol. 329, Apr. 2022, doi: 10.1016/j.conbuildmat.2022.127118.
22. T. Ozbakkaloglu, A. Gholampour, and T. Xie, "Mechanical and Durability Properties of Recycled Aggregate Concrete: Effect of Recycled Aggregate Properties and Content," Journal of Materials in Civil Engineering, vol. 30, no. 2, Feb. 2018, doi: 10.1061/(asce)mt.1943-5533.0002142.
23. A. . Sethia and S. R. Kumar, "Experimental Investigation of Recycled Aggregate Concrete Including Metakoline," SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology, vol. 14, no. 04, pp. 110–115, Dec. 2022, doi: 10.18090/samriddhi.v14i04.17.
24. M. Mulpuri, V. Sri, N. Sirisha, and T. Sujatha, "Mechanical properties of Recycled aggregate concrete with Portland slag cement," 2020. [Online]. Available: www.jetir.org
25. O. V. Vaidya, K. Malviya, and Y. L. Bhirud, "The strength characteristics of concrete using recycled concrete aggregates," Research on Engineering Structures and Materials, vol. 8, no. 4, pp. 853–860, Dec. 2022, doi: 10.17515/resm2022.423st0319tn.
26. P. P. Sivakumar, Y. A. Villagrán-Zaccardi, T. Lapauw, E. Gruyaert, S. Matthys, and N. De Belie, "Durability Performance of Hybrid Binder Concretes Containing Non-Ferrous Slag and Recycled Aggregates," Sustainability (Switzerland), vol. 15, no. 8, pp. 1–19, 2023, doi: 10.3390/su15086338.
27. S. K. Lin and C. H. Wu, "Improvement of bond strength and durability of recycled aggregate concrete incorporating high volume blast furnace slag," Materials, vol. 14, no. 13, Jul. 2021, doi: 10.3390/ma14133708.
28. C. Thomas, J. Setién, J. A. Polanco, P. Alaejos, and M. Sánchez De Juan, "Durability of recycled aggregate concrete," Constr Build Mater, vol. 40, pp. 1054–1065, Mar. 2013, doi: 10.1016/J.CONBUILDMAT.2012.11.106.
29. A. Abbas, G. Fathifazl, O. B. Isgor, A. G. Razaqpur, B. Fournier, and S. Foo, "Durability of recycled aggregate concrete designed with equivalent mortar volume method," Cem Concr Compos, vol. 31, no. 8, pp. 555–563, Sep. 2009, doi: 10.1016/J.CEMCONCOMP.2009.02.012.
30. H. Qasrawi, "The use of steel slag aggregate to enhance the mechanical properties of recycled aggregate concrete and retain the environment," Constr Build Mater, vol. 54, pp. 298–304, 2014.
31. A. Abbas et al., "Quantification of the residual mortar content in recycled concrete aggregates by image

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analysis," Mater Charact, vol. 60, no. 7, pp. 716–728, Jul. 2009, doi: 10.1016/j.matchar.2009.01.010.
32. M. Marvila, P. de Matos, E. Rodríguez, S. N. Monteiro, and A. R. G. de Azevedo, "Recycled Aggregate: A Viable Solution for Sustainable Concrete Production," Materials, vol. 15, no. 15, pp. 1–16, 2022, doi: 10.3390/ma15155276.
33. A. M. Knaack and Y. C. Kurama, "Parametric service load-deflection analyses of reinforced concrete beams with recycled concrete aggregates," ACI Struct J, vol. 117, no. 5, pp. 301–313, Oct. 2020, doi: 10.14359/51725846.
34. M. Hayles, L. F. M. Sanchez, and M. Noël, "Eco-efficient low cement recycled concrete aggregate mixtures for structural applications," Constr Build Mater, vol. 169, pp. 724–732, Apr. 2018, doi: 10.1016/j.conbuildmat.2018.02.127.

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