International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 15, Issue 08, August 2026)

Optimization of Al_2O_3 Content as a Partial Cement Replacement in Cement-Based Synthetic Tiles Incorporating Marble Slurry

Dr. Pramod Kumar Meena[1], Dr. Vivek Mishra[2], Dr. Veerendra Singh[3], Mr. Pramod Kumar Saini[4], Jyoti Choudhary[5]

[1,3]Assistant Professor Department of Chemistry, Government Raj Rishi College Alwar.
[2]Associate Professor Department of Chemistry, Government Raj Rishi College Alwar.
[4]Jouner Research Fellow Department of Chemistry, Government Raj Rishi College Alwar
[5]Lecturer, Department of Civil Engineering, Govt. Polytechnic College, Alwar (Raj)

***Abstract*-- The development of sustainable and high-performance construction materials has gained significant attention due to the environmental concerns associated with cement production and the increasing demand for eco-friendly building products. The utilization of industrial waste materials and suitable mineral additives in cementitious composites offers an effective approach to improving material performance while reducing cement consumption. In the present study, aluminum oxide (Al_2O_3) was investigated as a partial replacement for cement in cement-based synthetic tiles containing marble slurry. The primary objective of this research was to determine the optimum Al_2O_3 content and the best mix composition for achieving maximum compressive strength. Based on the findings of previous research, 10% marble slurry (by weight of fine aggregate and marble slurry) was adopted as a constant replacement level, as it had previously demonstrated the highest compressive strength. The experimental program utilized Ambuja Portland cement as the binder, river sand (675 g) as the fine aggregate, marble slurry and normal tap water added according to the required consistency. Al_2O_3 was incorporated as a partial replacement for cement at different replacement levels. For each mix proportion, three specimens were prepared, cured under standard conditions for 28 days, and tested for compressive strength. The results showed that the compressive strength increased progressively with increasing Al_2O_3 content up to 1.5% replacement of cement, after which a gradual reduction in strength was observed. The maximum compressive strength of 156 kN was obtained at the optimum replacement level of 1.5% Al_2O_3 with the following mix composition: [Cement: 246.25 g; Al_2O_3: 3.75 g (1.5% of cement); River Sand: 675 g; Marble Slurry: 75 g. The improvement in compressive strength is attributed to the filler effect and improved particle packing provided by Al_2O_3 at lower replacement levels, whereas excessive replacement reduced the effective cementitious matrix and consequently lowered the strength. The study concludes that1.5% Al_2O_3, in combination with the previously optimized 10% marble slurry, produces cement-based synthetic tiles with superior compressive strength and offers a sustainable alternative for construction applications through reduced cement consumption and beneficial utilization of industrial waste materials.**

***Keywords*-- Cement-based synthetic tile, Aluminum oxide (Al_2O_3), Marble slurry, Cement replacement, Sustainable construction, Compressive strength**

I. INTRODUCTION

The construction industry is one of the largest consumers of natural resources and cement worldwide. Ordinary Portland Cement (OPC) is the primary binding material used in concrete, mortar, tiles, and other construction products due to its excellent mechanical properties and durability. However, cement manufacturing is an energy-intensive process and is recognized as a major contributor to global greenhouse gas emissions. It is estimated that the production of one tonne of Portland cement releases approximately 0.8–0.9 tonnes of carbon dioxide (CO_2) into the atmosphere through limestone calcination and fuel combustion [1]-[2]. Consequently, the cement industry accounts for nearly 7–8% of global anthropogenic CO_2 emissions [1]. With increasing concerns regarding climate change and sustainable development, reducing cement consumption without compromising the performance of construction materials has become an important research objective. One of the most effective approaches for reducing the environmental impact of cement-based materials is the partial replacement of cement with supplementary materials or mineral additives. Such replacements can lower the carbon footprint of construction products while maintaining or even improving their engineering properties. In addition to reducing cement consumption, the utilization of industrial by-products and waste materials contributes to sustainable waste management by diverting large quantities of waste from landfills and reducing the extraction of natural resources.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 15, Issue 08, August 2026)

Among various industrial wastes, marble slurry has attracted considerable attention because of its large-scale generation during the cutting and polishing of marble stones.[3]-[4] The marble processing industry produces significant quantities of fine slurry, which is often disposed of in open areas or water bodies, causing serious environmental problems such as soil degradation, dust pollution, and blockage of drainage systems. Owing to its high calcium carbonate content and fine particle size, marble slurry has been successfully incorporated into cementitious materials as a filler or partial replacement for fine aggregate and cement [5]. Previous investigations have demonstrated that the incorporation of an optimum amount of marble slurry improves particle packing, reduces voids, and enhances the mechanical properties of cement-based composites[6]-[7]. Based on previous experimental investigations, 10% marble slurry (by weight of fine aggregate) was found to provide the highest compressive strength and was therefore selected as the fixed marble slurry content in the present study[3],[7]. In recent years, synthetic cement-based tiles have gained increasing popularity in residential, commercial, and industrial construction because of their high strength, dimensional stability, ease of manufacturing, attractive appearance, and cost-effectiveness. Compared with natural stone tiles, synthetic tiles offer greater flexibility in shape, texture, and colour while reducing dependence on natural stone resources [8]. Improving the mechanical performance of synthetic tiles through optimized material composition remains an important area of research to enhance their service life and broaden their structural applications. Aluminum oxide (Al_2O_3) has emerged as a promising mineral additive for cementitious composites due to its high hardness, chemical stability, and fine particle size. Researchers have reported that the incorporation of Al_2O_3 in cement-based materials can improve compressive strength, abrasion resistance, and microstructural density, particularly when used at low replacement levels [9]-[11]. The improvement is generally attributed to the micro-filler effect, refinement of pore structure, and enhancement of particle packing within the cement matrix. However, excessive replacement of cement with Al_2O_3 may reduce the quantity of cementitious binder available for hydration, resulting in a decline in mechanical strength [12]. Therefore, determining the optimum Al_2O_3 replacement level is essential for maximizing the performance of cement-based composites.

Several studies have investigated the use of supplementary cementitious materials such as fly ash, silica fume, ground granulated blast furnace slag, metakaolin, rice husk ash, and marble powder in cement-based materials[13]-[14].

Similarly, numerous researchers have evaluated the beneficial effects of marble slurry on the mechanical and durability properties of mortar, concrete, and paving products[15]-[17]. Although Al_2O_3 has also been investigated as a modifier in cementitious systems, most published studies focus on concrete, mortar, or high-performance cement composites. Comparatively fewer investigations have examined its application in cement-based synthetic tiles, particularly in combination with a previously optimized marble slurry content. Furthermore, limited information is available regarding the optimum percentage of Al_2O_3 required to maximize the compressive strength of such tile composites.

Although previous studies have independently demonstrated the beneficial effects of marble slurry and Al_2O_3 in cementitious materials, limited research has investigated the combined use of these materials in cement-based synthetic tiles. In particular, there is insufficient information on the optimization of Al_2O_3 content when 10% marble slurry is maintained as a fixed component of the mix. Consequently, the optimum Al_2O_3 replacement level for achieving maximum compressive strength in cement-based synthetic tiles remains inadequately understood. The present investigation aims to optimize the percentage of Al_2O_3 as a partial replacement for cement in cement-based synthetic tiles containing a fixed 10% marble slurry replacement of fine aggregate. The specific objectives of the study are:

1. To prepare cement-based synthetic tiles containing 10% marble slurry and varying percentages of Al_2O_3 as a partial replacement for cement.
2. To evaluate the 28-day compressive strength of each mix using three specimens per composition.
3. To determine the optimum Al_2O_3 replacement level that provides the maximum compressive strength.
4. To assess the suitability of Al_2O_3-modified cement-based synthetic tiles as a sustainable construction material with reduced cement consumption and effective utilization of marble industry waste.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 15, Issue 08, August 2026)

II. Materials Used

The materials used in the present investigation consisted of (i) Ordinary Portland Cement (OPC) 53 Grade (Ambuja Cement) as the primary binding material because of its high early strength and wide use in construction applications (ii) river sand as the fine aggregate after ensuring it was free from organic impurities and deleterious materials, (iii) dry marble slurry powder obtained from the marble processing industry was incorporated as a partial replacement for fine aggregate based on the optimum percentage reported in previous studies, (iv) Al_2O_3 powder was used as a partial replacement for cement at different replacement levels and (v) Normal potable tap water was used for mixing and curing of all specimens.

III. Experimental Methodology

A. Mix Proportions

The experimental program was designed to investigate the effect of aluminum oxide (Al_2O_3) as a partial replacement for cement on the compressive strength of cement-based synthetic tiles. Based on the results of previous studies, the marble slurry content was maintained at 10% of the fine aggregate in all mixes, while the percentage of Al_2O_3 was varied to determine its optimum replacement level (Show in table – I). River sand content was kept constant for all mixes.

TABLE I
MIXED PROPORTIONS OF CEMENT BASED SYNTHETIC TILES

Mix ID	Cement (gm)	(Al_2O_3) (gm)	Al_2O_3 (% by wt. of cement)	Marble Slurry (gm)	River Sand (gm)
M1	250	0	0	75	675
M2	248.75	1.25	0.5	75	675
M3	247.5	2.5	1	75	675
M4	246.25	3.75	1.5	75	675
M5	245	5	2	75	675
M6	243.75	6.25	2.5	75	675

B. Mixing Procedure

The required quantities of Ordinary Portland Cement (OPC 53 Grade), river sand, dry marble slurry powder, and Al_2O_3 powder were weighed accurately according to the selected mix proportions. Initially, the dry materials were thoroughly mixed until a uniform blend was obtained. Subsequently, the required quantity of tap water was added gradually while mixing continuously to produce a homogeneous and workable mixture.

Care was taken to ensure uniform distribution of Al_2O_3 and marble slurry throughout the mix and to avoid segregation or formation of lumps.

C. Casting of Specimens

The freshly prepared mix was poured into clean and properly lubricated moulds in layers. Each layer was compacted manually to remove entrapped air and achieve proper compaction. The top surface of each specimen was levelled using a trowel to obtain a smooth and uniform finish.

D. Demoulding

The cast specimens were kept undisturbed under laboratory conditions for 48 hours. After the initial setting period, the specimens were carefully removed from the moulds to prevent any damage to their edges and surfaces.

E. Curing

After demoulding, all specimens were immersed in clean water and cured under standard laboratory conditions for 28 days. Continuous water curing was maintained throughout the curing period to ensure adequate hydration of the cementitious materials and proper development of strength.

F. Number of Specimens

A total of 18 specimens were prepared for the experimental investigation. Each mix proportion was represented by three identical specimens, and the average compressive strength of the three specimens was considered as the representative value for analysis and comparison.

IV. Results And Discussion

A. Compressive Strength Versus Al_2O_3 Percentage

The compressive strength of the cement-based synthetic tile specimens was evaluated after 28 days of curing. For each mix proportion, three specimens were tested, and the average compressive strength was considered for comparison. The marble slurry content was maintained constant at 10% of the fine aggregate, while the Al_2O_3 content was varied as a partial replacement of cement. The variation in compressive strength with different Al_2O_3 replacement levels is presented in Table -2.

The results indicate a clear relationship between Al_2O_3 content and compressive strength. With the gradual increase in Al_2O_3 content, the compressive strength increased up to a certain replacement level. The strength enhancement at lower Al_2O_3 contents may be associated with the fine particle size of Al_2O_3, which can contribute to improved particle packing and a denser cementations matrix.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 15, Issue 08, August 2026)

The presence of finely distributed Al_2O_3 particles may also help to reduce internal voids and improve the compactness of the composite. However, beyond the optimum replacement level, the compressive strength showed a decreasing trend. Excessive replacement of cement with Al_2O_3 may reduce the effective quantity of cement available for hydration and binder formation. Consequently, the beneficial filler effect is no longer sufficient to compensate for the reduction in the cementations phase, resulting in a decline in compressive strength.

TABLE-2.
COMPRESSIVE STRENGTH WITH AL_2O_3 REPLACEMENT LEVELS

Experiment Number	% of Al_2O_3	Compressive Strength in Kilonewton (kN)			
		Set -I	Set -II	Set -III	Average
1	0	105	105	107	105.66
2	0.5	115	115	118	116.00
3	1	155	152	152	153.00
4	1.5	157	155	156	156.00
5	2	146	142	143	143.66
6	2.5	113	115	116	114.66

B. Comparison with the Control Mix

The mix containing 0% Al_2O_3 was considered the control mix. The compressive strength obtained from the modified mixes was compared with that of the control specimen to determine the influence of Al_2O_3 incorporation. The maximum compressive strength obtained in the present investigation was 156 kN, which was recorded at1.5% Al_2O_3 replacement of cement. Compared with the control mix, the 1.5% Al_2O_3 mix demonstrated a significant improvement in load-bearing capacity. This indicates that a controlled quantity of Al_2O_3 can positively influence the mechanical performance of the cement-based synthetic tile containing marble slurry.

V. Conclusion

The present study investigated the effect of Al_2O_3 as a partial replacement for cement in cement-based synthetic tiles incorporating a fixed 10% marble slurry content. Based on the compressive strength results, the following conclusions can be drawn:

1. Al_2O_3 significantly influenced the compressive strength of the cement-based synthetic tiles. The incorporation of Al_2O_3 produced a distinct variation in strength depending on its replacement level.
2. The optimum Al_2O_3 replacement level was found to be 1.5% by weight of cement. At this replacement level, the tiles exhibited the highest compressive strength among the investigated compositions.
3. Compressive strength increased with increasing Al_2O_3 content up to1. 5%. The maximum compressive strength of 156 kN was obtained at 1.5% Al_2O_3. Beyond this optimum level, the compressive strength decreased, indicating that excessive replacement of cement with Al_2O_3 is not beneficial under the conditions of the present study.
4. Marble slurry was successfully utilized as a component of the synthetic tile mix. A fixed 10% marble slurry by weight of fine aggregate was incorporated based on previous experimental findings, thereby providing a beneficial application for marble-processing waste.
5. The combined use of 10% marble slurry and 1.5% Al_2O_3 resulted in the optimum composition investigated in this study, demonstrating the potential of the developed material for producing cement-based synthetic tiles with improved compressive strength.
6. Partial replacement of cement with Al_2O_3 reduced the quantity of conventional cement required for the tile mixture. Therefore, the developed composite has potential to contribute to more sustainable construction materials while simultaneously promoting the utilization of marble waste.

Overall, the findings demonstrate that the optimized incorporation of 1.5% Al_2O_3 with 10% marble slurry can improve the compressive strength of cement-based synthetic tiles and provide a promising approach for the development of more sustainable construction products. Further studies involving durability, water absorption, abrasion resistance, microstructural analysis, and long-term performance are recommended to establish the broader applicability of the developed tiles.

VI. Future Scope

Further investigations are required to evaluate the long-term performance, durability, economic feasibility, and practical applicability of the developed material. The following areas are recommended for future research

1. Long-term durability studies: The performance of the optimized tile composition should be investigated over longer curing and exposure periods to evaluate strength development and durability under different environmental conditions.

2. Freeze–thaw resistance: Although the present study was conducted under standard laboratory curing conditions, future research should evaluate the resistance of the developed tiles to repeated freeze–thaw cycles to assess their suitability for applications exposed to severe temperature variations.
3. Microstructural analysis: Advanced characterization techniques such as Scanning Electron Microscopy (SEM), X-ray Diffraction (XRD), and Fourier Transform Infrared Spectroscopy (FTIR) can be employed to investigate the morphology, crystalline phases, hydration products, bonding characteristics, and microstructural changes associated with Al_2O_3 and marble slurry incorporation. These analyses can provide a better understanding of the mechanisms responsible for the observed improvement in compressive strength.
4. Industrial-scale production: Further research is required to assess the feasibility of producing the optimized cement-based synthetic tiles on an industrial scale. Factors such as mixing efficiency, moulding methods, curing conditions, production consistency, and quality control should be investigated before large-scale implementation.
5. Cost and life-cycle assessment: A detailed economic analysis should be performed to determine the cost-effectiveness of the optimized tile composition. In addition, life-cycle assessment (LCA) should be conducted to quantify potential reductions in cement consumption, waste disposal, energy use, and greenhouse gas emissions compared with conventional tile production.

Overall, these investigations would help establish the technical, environmental, and economic feasibility of Al_2O_3-modified cement-based synthetic tiles containing marble slurry and support their potential transition from laboratory-scale research to practical construction applications.

Acknowledgements

The authors gratefully acknowledge the financial assistance and research support provided under the RUSA 2.0 Research Project entitled *"Exploitation of Marble Slurry to Minimize Environmental Hazards in Rajasthan and its Use in Synthetic Tiles – An Eco-Friendly Approach."* The authors express their sincere gratitude to the Principal, Raj Rishi Government Autonomous College, Alwar, for the administrative assistance and cooperation extended by the college authorities, which enabled the experimental work to be carried out smoothly.

The authors also sincerely acknowledge the support and cooperation received from the Department of Chemistry, Raj Rishi Government Autonomous College, Alwar**.** The authors are grateful to the faculty members, laboratory staff, and technical personnel for their valuable assistance in material preparation, specimen preparation, laboratory work, and other activities associated with the research. The authors are highly grateful to the Public Works Department (PWD), Alwar**,** for extending the required laboratory facilities and providing technical assistance for conducting the compressive strength testing of specimens. The authors also acknowledge the contribution of all personnel involved in the collection, preparation, and handling of the marble slurry used in this investigation. The authors further extend their appreciation to other supporting staff who provided their valuable time, suggestions, technical assistance, and cooperation during different stages of the research. Their support contributed significantly to the successful completion of the experimental programme.

REFERENCES

[1] K. L. Scrivener, V. M. John, and E. M. Gartner, "Eco-efficient cements: Potential, economically viable solutions for a low-CO_2 cement-based materials industry," *Cement and Concrete Research*, vol. 114, pp. 2–26, Dec. 2018, doi: 10.1016/j.cemconres.2018.03.015.

[2] Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, U.K.: Cambridge University Press, 2022.

[3] B. Singh, M. Gupta, and S. K. Bhattacharyya, "Feasibility as a Potential Substitute for Natural Sand: A Comparative Study between Granite Cutting Waste and Marble Slurry," *Procedia Environmental Sciences*, vol. 35, pp. 571–582, 2016, doi: 10.1016/j.proenv.2016.07.042.

[4] S. Luhar and I. Luhar, "Sustainable Recycling and Reuse of Marble Waste in the Construction Industry: A Systematic Review Towards a Circular Economy," *Journal of Composites Science*, vol. 10, no. 5, Art. 221, 2026, doi: 10.3390/jcs10050221

[5] Rana, P. Kalla, and L. J. Csetenyi, "Sustainable use of marble slurry in concrete," *Journal of Cleaner Production*, vol. 94, pp. 304–311, May 2015, doi: 10.1016/j.jclepro.2015.01.053.

[6] A. Aliabdo, A. E. M. Abd Elmoaty, and E. M. Auda, "Re-use of waste marble dust in the production of cement and concrete," *Construction and Building Materials*, vol. 50, pp. 28–41, Jan. 2014, doi: 10.1016/j.conbuildmat.2013.09.005.

[7] V. Corinaldesi, G. Moriconi, and T. R. Naik, "Characterization of marble powder for its use in mortar and concrete," *Construction and Building Materials*, vol. 24, no. 1, pp. 113–117, Jan. 2010, doi: 10.1016/j.conbuildmat.2009.08.013.

[8] M. E. Allam, S. K. Amin, and G. Garas, "Testing of cementitious roofing tile specimens using marble waste slurry," *International Journal of Sustainable Engineering*, vol. 13, no. 2, pp. 151–157, 2020, doi: 10.1080/19397038.2019.1657981.

[9] W. Iskra-Kozak and J. Konkol, "The Impact of Nano-Al_2O_3 on the Physical and Strength Properties as Well as on the Morphology of Cement Composite Crack Surfaces in the Early and Later Maturation Age," *Materials*, vol. 14, no. 16, Art. no. 4441, 2021, doi: 10.3390/ma14164441.

[10] Sadowski and Ł. Sadowski, "The Development of Nanoalumina-Based Cement Mortars for Overlay Applications in Concrete Floors," *Materials*, vol. 12, no. 20, Art. no. 3295, 2019, doi: 10.3390/ma12203295.

[11] Sadowski and Ł. Sadowski, "The Development of Nanoalumina-Based Cement Mortars for Overlay Applications in Concrete Floors," *Materials*, vol. 12, no. 20, Art. no. 3295, 2019, doi: 10.3390/ma12203295.

[12] W. Iskra-Kozak and J. Konkol, "The Impact of Nano-Al_2O_3 on the Physical and Strength Properties as Well as on the Morphology of Cement Composite Crack Surfaces in the Early and Later Maturation Age," *Materials*, vol. 14, no. 16, Art. no. 4441, 2021, doi: 10.3390/ma14164441.

[13] K. L. Scrivener, F. Martirena, S. Bishnoi, and S. Maity, "Calcined clay limestone cements (LC3)," *Cement and Concrete Research*, vol. 114, pp. 49–56, 2018, doi: 10.1016/j.cemconres.2017.08.017.

[14] B. Prakash, T. J. Saravanan, K. I. S. A. Kabeer, and K. Bisht, "Exploring the potential of waste marble powder as a sustainable substitute to cement in cement-based composites: A review," *Construction and Building Materials*, vol. 401, Art. no. 132887, 2023, doi: 10.1016/j.conbuildmat.2023.132887.

[15] A. Rana, P. Kalla, and L. J. Csetenyi, "Sustainable use of marble slurry in concrete," *Journal of Cleaner Production*, vol. 94, pp. 304–311, May 2015, doi: 10.1016/j.jclepro.2015.01.053.

[16] A. A. Aliabdo, A. E. M. Abd Elmoaty, and E. M. Auda, "Re-use of waste marble dust in the production of cement and concrete," *Construction and Building Materials*, vol. 50, pp. 28–41, Jan. 2014, doi: 10.1016/j.conbuildmat.2013.09.005.

[17] A. O. Mashaly, B. A. El-Kaliouby, B. N. Shalaby, A. M. El-Gohary, and M. A. Rashwan, "Effects of marble sludge incorporation on the properties of cement composites and concrete paving blocks," *Journal of Cleaner Production*, vol. 112, pp. 731–741, 2016, doi: 10.1016/j.jclepro.2015.07.023.