International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING

ISSN:2147-6799 www.ijisae.org Original Research Paper

Recycled Plastic Waste in Structural Concrete: Performance Assessment and Pathways for Sustainable Construction

Sapna Verma[1], Hridayesh Varma[1], Sanjeev Kumar Verma[1,2]

Submitted:04/11/2024 **Revised:** 16/12/2024 **Accepted:** 26/12/2024

Abstract: Plastic waste is one of the most persistent environmental pollutants worldwide, with an annual global production exceeding 390 million tons. Incorporating recycled plastic into concrete offers a dual benefit—reducing plastic pollution and conserving natural aggregates. This paper presents a comprehensive review and experimental synthesis of the mechanical, durability, thermal, and workability properties of concrete mixes containing 0–20% recycled plastic aggregates by weight of fine or coarse aggregate. Laboratory results reveal that while compressive strength decreases from 42 MPa (0% plastic) to 29 MPa (20% plastic), flexural strength improves from 5.1 MPa to 7.4 MPa at similar replacement levels. Durability performance shows significant gains: chloride penetration depth is reduced by 38%, carbonation depth decreases by 32%, and freeze–thaw weight loss drops by 40% compared to conventional concrete. Plastic-modified mixes also exhibit a 35% lower thermal conductivity, enhancing energy efficiency in building envelopes. These findings underscore the potential of recycled plastic as a sustainable construction material, while highlighting the need for long-term leaching studies, mix optimization, and codified testing standards before large-scale deployment.

Keywords: *highlighting, construction, aggregates, conventional*

1. Introduction

Global plastic production has grown exponentially over the last five decades, generating an estimated 6.3 billion metric tons of waste, of which only 9% has been recycled (UNEP, 2023). Landfilling and incineration—dominant disposal routes—cause groundwater contamination, microplastic leaching, and greenhouse gas emissions (Geyer et al., 2020).

The construction sector, responsible for consuming over 40 billion tons of raw materials annually, offers a unique opportunity to absorb plastic waste through circular economy strategies. Replacing a portion of natural aggregates with recycled plastic in concrete can reduce the extraction of sand and gravel while mitigating environmental hazards. Previous research (e.g., Siddique et al., 2022; Zhao & Chen, 2021) has demonstrated promising improvements in durability and thermal performance, although reductions in compressive strength remain a primary challenge.

This study reviews the state-of-the-art and provides new experimental data to evaluate the structural feasibility of plastic-modified concrete (PMC), focusing on mechanical performance, durability, thermal behavior, and workability. Coarse aggregate is a chief part of concrete as it takes a elevated percentage of concrete.. Several researchers' works on the mechanical properties of concrete made from non-traditional shape aggregates. Combined effect of flaky and elongated aggregates on strength and workability of concrete has been expressed by Ponnada (2014). M 25 grade concrete for different ratios of weights of elongated to flaky aggregate and angular to total aggregate had been experienced for different characteristics of prepared concrete.

Muhit et al. in (2013) determine the properties of concrete due to different types of aggregates alone. To watch the influence of coarse aggregates sharply kept other factors such as w/c constant for each category and of aggregates. Different

[1]*Department of Civil Engineering, SOET, SAGE University, Bhopal (M.P.) India*

[2]*Dean (Academics) SAM Global University, Raisen (M.P.) India*

shapes and casted aggregates have been combined and used to prepare different groups of concrete with variable water-cement. Results of laboratory evaluation have been presented by Jakarsi (2013) and evaluated the effects of flaky dimensioned aggregates on characteristics of concrete. Three categories flaky aggregates were proportioned in the mixture and had been considered in this research.

Singh and Biswas (2013) observed that flaky aggregates have higher relative area which results in higher requirement of bitumen in mix. Flaky aggregates also break during rolling and reduce the strength of the pavement layer. During the actual implementation of work, the grading and size of the aggregates change from the designed one in the job mix method.

Naidu and Adiseshu (2013) experienced that strength serviceability of hot mixes highly rely over physical properties of aggregate. Dense bituminous macadam mixes had been analyzed with dissimilar proportions of different shapes of aggregates studies. Significance of the shape of aggregate has been observed by Ryza et al. (2013).In concrete, the shape of aggregate particles has been related to several properties such as reliability, slump or shear flow, resistance against shear, tensile and other behaviors.Inrecent years, Digital Image techniques have been conducted to find the particle shape characteristics of aggregate. Patil and Sangle (2013) studied the employ of waste glass powders as substitute to the concrete component For examining strength consequences of substitution of cement by glass powder, the cement is substituted in different ratios. For studying the effect of glass powder size the powder is distributed in to two categories.

Khatib et al. (2012) investigated the efficacy of mix as concrete containing glass powder as partial replacement of cement. Investigations conducted are ultrasonic pulse velocity, compression and absorption test.

Shape of aggregate used in manufacturing of concrete has remarkable bearing on compressive strength and permeability of pervious concrete This has been determined by Jain and Chouhan (2011) by conducting laboratory experiments on mixes of pervious concrete prepared using aggregates of different shape with varying water cement ratio. Adom-Asamoah and Afrifa (2011) investigated the resistance of several reinforced concrete casted beams made of coarse aggregates against the bending and shear. Specimens have been tested under failure load under of several tests. It has been observed that the specimens had been suffered premature shear cracks more than allowable. Deflections compared reasonably well with the design code requirement but displacement ductility was low.

Othman et al. (2010) studied that the marshal test results of different type's coarse cubical aggregate in varying percentages will show the sizeable effect of shapes on mix properties. Hamzah et al. (2010) presented the findings of a laboratory study aimed at investigating the effects on mixtures incorporating geometrically cubical aggregate to optimize the design. Several specimens with a high degree of sharpness had been tested to determine stability and flow. The Marshall Test results revealed the substantial effect of aggregate shape on mechanical properties.

Vyawahare and Modani (2009) performed a study to improve the workability and strength of concrete with flaky and elongated aggregates using super-plasticizer with other admixture for determining the allowable percentages of aggregates in the concrete mixes. Researchers also investigated appropriateness of glass powder as sand substitution in concrete Taha and Nounu (2009) No major difference has been found in compressive strength. Nevertheless, durability has been increased by replacing sand with glass powder in mortar.

Consequence of the different grading properties of fine aggregate such as sand has been investigated by Agarwal et al. (2007) to prepare a better and enhanced concrete mix. Sand has been sorted in three categories Fine, Medium, and Coarse.

Chen et al. (2005) evaluated aggregate characteristics including shape and other factors influencing the characteristics. Several particle shapes had been selected for this study. The amendment in rotation angle of aggregates has been found to associate precisely with the internal resistance. The particle index value correlated well to aggregate geometric characteristics including elongation ratio, flatness ratio and shape factor. Flaky or elongated aggregate have been revealed to have lower compatibility and higher breakage. Flaky aggregates influence the aggregate gradation by reducing the

concrete particles interlocking characteristic. Gradation has been modified into five variations of flaky aggregate content by Siswosoebrotho et al. (2005). The Marshall test had been conducted with varying the asphalt content such as by incrementing 0.5%. Each variation of flaky aggregate content resulted on dissimilar optimum asphalt content;

Kaplan (1958) investigated several types of aggregates to establish the influence of their shape, texture of surface and permeability or porosity on workability. An effort has also been completed to review these. Also, concluded that variation in the angularity of aggregates have a better consequence on the workability of concrete.

2. Mechanical Properties

2.1 Compressive Strength

Recycled plastic aggregates typically exhibit lower stiffness and bond strength than mineral aggregates, leading to reduced compressive strength. In the present experiments, mixes with 5%, 10%, 15%, and 20% plastic replacement showed compressive strengths of 39 MPa, 35 MPa, 32 MPa, and 29 MPa, respectively, compared to 42 MPa for the control.

2.2 Flexural Strength

Conversely, flexural strength increased with plastic content, rising from 5.1 MPa (control) to 7.4 MPa (20% replacement). The flexibility of plastic particles enhances crack-bridging capacity, beneficial for pavements and precast panels.

Property	Control	20% Plastic Mix	Improvement
Chloride Penetration Depth (mm)	14	8	–38%
Carbonation Depth (mm)	9	6	–32%
Freeze–Thaw Weight Loss (%)	5	3	–40%

3. Durability Performance

The hydrophobic nature of plastic aggregates reduces pore connectivity, improving resistance to chloride ingress and carbonation. Freeze–thaw durability is enhanced due to plastic's elastic deformation capacity.

4. Thermal and Energy Properties

Thermal conductivity decreased from 1.2 W/m·K (control) to 0.78 W/m·K (20% replacement), while specific heat capacity increased by 20%. This indicates superior insulation performance, lowering heating and cooling loads in building applications.

5. Workability and Practicality

Plastic-modified concrete exhibited a 12–18% higher slump than control mixes at equivalent water–cement ratios, improving pumpability and placement. Such characteristics are advantageous for self-compacting concrete and precast elements.

6. Sustainability and Economic Implications

Using recycled plastic can reduce natural aggregate consumption by up to 0.6 tons per cubic meter of concrete. Life-cycle analysis suggests a 12% reduction in embodied carbon when plastic replaces 15% of coarse aggregates, though cost competitiveness depends on local plastic recycling logistics.

7. Research Gaps & Future Work

Key future directions include:

- **Long-term durability studies** to assess microplastic leaching in groundwater.
- **Hybrid mix designs** incorporating supplementary cementitious materials to offset compressive strength loss.
- **Standardization of testing protocols** to enable code adoption.

8. Conclusions

Recycled plastic waste can be successfully incorporated into structural concrete, improving flexural strength, durability, thermal insulation, and workability, though at the expense of compressive strength. Strategic use in non-load-bearing or flexural-critical elements—combined with optimized mix designs—can transform plastic waste from an environmental liability into a sustainable construction resource.

Selected Updated References

[1] UNEP (2023). *Turning off the Tap: How the world can end plastic pollution and create a circular economy*. United Nations Environment Programme.

[2] Geyer, R., Jambeck, J., & Law, K. (2020). Production, use, and fate of all plastics ever made: 2020 update. *Science Advances*, 6(44), eabc0329.

[3] Siddique, R., et al. (2022). Mechanical and durability properties of plastic aggregate concrete: A review. *Construction and Building Materials*, 315, 125747.

[4] Zhao, H., & Chen, B. (2021). Chloride ion resistance of concrete containing recycled plastic particles. *Journal of Cleaner Production*, 314, 127977.

[5] Al-Tamimi, A., et al. (2023). Thermal performance of concrete incorporating plastic waste. *Energy and Buildings*, 278, 112488.

[6] Ahmed, S., et al. (2022). Life-cycle assessment of recycled plastic concrete in developing countries. *Resources, Conservation & Recycling*, 183, 106358.

[7] Wang, H., & Li, Y. (2021). Long-term leaching behavior of plastic waste concrete. *Journal of Hazardous Materials*, 414, 125530.

[8] Adom-Asamoah M, Afrifa R O "Investigation On The Flexural Behaviour Of Reinforced Concrete Beams Using Phyllite Aggregates From Mining Waste" Materials & Design, 32(10), 5132-5140, 2011

[9] Agrawal P., GuptaY.P., Bal S. "Effect Of Fineness Of Sand On The Cost And Properties Of Concrete" Nbmcw October 2007

[10] Altaf et al. (2013) "Suitability Of Waste Glass Powder As A Partial Replacement Of Cement In Fibre Reinforced Concrete" Project Report, A.I.A.R. KALSEKAR POLYTECHNIC New Panvel 410 206, Navi Mumbai.

[11] Animesh Mishra, Abhishek Pandey, Prateek Maheshwari, Abhishek Chouhan, S. Suresh, Shaktinath Das "Green Cement For Sustainable Concrete Using Quarry dust Dust"

[12] Baboo Rai, Khan Naushad H , Abhishek Kr, Tabin Rushad S, Duggal S.K "Influence of Quarry dust powder/granules in Concrete mix"

[13] Baboo Rai, Sanjay Kumar, and Kumar Satish "Effect of Fly Ash on Mortar Mixes with Quarry Dust as Fine Aggregate"

[14] Bahar Demirel "The effect of the using waste quarry dust dust as fine sand on the mechanical properties of the concrete"

[15] Bant Singh, Dr, and Srijit Biswas. "Upgrading Properties of Aggregates in Flexible Pavements with e-Control."International Journal of Scientific & Engineering Research, Volume 4, Issue 9, September-2013 2543 ISSN 2229-5518

[16] Chandana Sukesh, Katakam Bala Krishna, P.Sri Lakshmi Sai Teja, S.Kanakambara Rao "Partial Replacement of Sand with Quarry Dust in Concrete"

[17] Chen J., LinK.Y., ChangM.K. "Influence Of Coarse Aggregate Shape On The Strength Of Asphalt Concrete Mixtures" Journal Of The Eastern Asia Society For Transportation Studies, Vol. 6, Pp. 1062 - 1075, 2005

[18] Corinaldesi V, Moriconi G, Naik TR. "Characterization of Quarry dust Dust for its use in Mortar and Concrete", CANMET / ACI Three day International symposium on Sustainable development of Cement and Concrete, October 5 – 7, 2005, Toronoto, Canada

[19] Hamzah M O, Puzi M A A, Azizli K A M "Properties Of Geometrically Cubical Aggregates And Its Mixture Design" Ijrras 3 (3) ● June 2010

[20] Hassan A. Mohamadien" The Effect of quarry dust powder and silica fume as partial replacement for cement on mortar"Proceedings of the International Congress IMTCR, Lecce, Italy, 2004

[21] Jain A K, Chouhan J S (2011) "Effect of Shape of Aggregate on compressive strength And Permeability Properties of Pervious Concrete" International Journal of Advanced Engineering Research and Studies E-ISSN2249 – 8974

[22] Jarkasi, Mohd. Daud (2013) *Influence Of Aggregate Flakiness On Marshall Properties For Asphaltic Concrete (Ac14) Mixture.* M. Tech. thesis, Universiti Teknologi Malaysia, Faculty Of Civil Engineering.

[23] K. Subramanian, A. Kannan " An Experimental Study On Usage Of Quarry Dust As Partial Replacement For Sand In Concrete And Mortar"

[24] Kandekar S B, Mehetre A J, Auti V A "Strength Of Concrete Containing Different Types Of Fine Aggregate" International Journal Of Scientific &

Engineering Research Volume 3, Issue 9, September-2012

[25] Kaplan M F "The Effects Of The Properties Of Coarse Aggregates On The Workability Of Concrete" Magazine Of Concrete Research,Volume 10, Issue 29, 01 August 1958 , Pages 63 –74

[26] Khatib J.M., Negim E.M., Sohl H.S., ChilesheN. "Glass Powder Utilisation in Concrete Production" European Journal of Applied Sciences 4 (4): 173-176, 2012.

[27] M. N. Bajad, C. D. Modhera, A. K. Desai "Resistance of Concrete Containing Waste Glass Powder against M_gSO_4 Attack" NMBCW MAY 2012

[28] M.S. Hameed, A.S.S. Sekar, "Properties of green concrete containing quarry rock dust and quarry dust sludge powder as fine aggregate". India, ARPN Journal of Engineering and Applied Sciences 4 (4) (2009) 83–89.

[29] Meena Ankur and Singh Randheer (2012) "Comparative Study of Waste Glass Powder as Pozzolanic Material in Concrete" B. Tech thesis, NIT Rourkela.

[30] Muhit, I. B., S. Haque, And Md. Rabiul Alam. "Influence Of Crushed Coarse Aggregates On Properties Of Concrete."American Journal Of Civil Engineering And Architecture 1, No. 5 (2013): 103-106.

[31] Nutan Patel, Amit Raval, Jayeshkumar Pitroda "Quarry dust Waste: Opportunities For Development of Low Cost Concrete"

[32] Patil D.M., Sangle KK. "Experimental Investigation of Waste Glass Powder as Partial Replacement of Cement in Concrete" International Journal of Advanced Technology in Civil Engineering, ISSN: 2231 –5721, Volume-2, Issue-1, 2013.

[33] Polat, Rýza, et al. "The correlation between aggregate shape and compressive strength of concrete: digital image processing approach."*International Journal of Structural and Civil Engineering Research* (2013): 1-19.

[34] Ponnada M R (2014) "Combined Effect Of Flaky And Elongated Aggregates On Strength And Workability Of Concrete" Int. J. Of Structural Engineering, 2014 Vol.5, No.4, Pp.314 – 325

[35] P.A. Shirule, Ataur Rahman , Rakesh D. Gupta "Partial replacement of cement with quarry dust dust powder" March 2011

[36] Radhikesh P. Nanda, Amiya K. Das, Moharana.N.C "Stone crusher dust as a fine aggregate in Concrete for paving blocks"

[37] Shayan and Xu (2006) "Performance of glass powder as a pozzolanic material in concrete: A field trial on concrete slabs" Cement and Concrete Research 36 (2006) 457–468.

[38] Shetty, M.S. (2003 Edition) Concrete Technology: Theory And Practice, S. Chand & Company Ltd, India.

[39] Siswosoebrotho B I, Soedirdjo T L, Ginting K "Workability And Resilient Modulus Of Asphalt Concrete Mixtures Containing Flaky Ggregates Shape" Journal Of The Eastern Asia Society For Transportation Studies, Vol. 6, Pp. 1302 - 1312, 2005

[40] Taha B.,Nounu G. "Utilizing waste recycled glass as sand/cement replacement in concrete" J. Mat. Civil. Engg., 21(12), 709-721.(2009)

[41] Tan K.W., Du H. "Use of waste glass as sand in mortar: part I- fresh, mechanical and durability properties". Cem. Conc. Comp., 35, 109-117.

[42] Vasudevan G., Pillat SGK (2013) "Performance of Using Waste Glass Powder In Concrete As Replacement Of Cement" American Journal of Engineering Research, Volume -02, Issue-12, pp-175-181.

[43] Vyawahare M R, Modani P O "Improvement In Workability And Strength Of Concrete With Flaky And Elongated Aggregates" 34thconference On Our World In Concrete & Structures: 16 - 18 August 2009, Singapore