Microstructural Analysis of Crumb Rubber Concrete Using Scanning Electron Microscope

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Abstract—**The utilization of waste tyre rubber in concrete has emerged as an environmentally sustainable approach to reducing solid waste while conserving natural aggregates. However, the incorporation of crumb rubber modifies the internal microstructure of concrete, thereby influencing its mechanical and durability characteristics. This study presents a microstructural investigation of M30 grade crumb rubber concrete using Scanning Electron Microscope (SEM). Concrete specimens containing crumb rubber as a partial replacement for coarse aggregate were examined to evaluate the morphology of hydration products, pore distribution, interfacial transition zone (ITZ), and crack formation. SEM observations revealed that conventional concrete exhibited a relatively dense microstructure with well-developed calcium silicate hydrate (C–S–H) gel and fewer micro voids. In contrast, crumb rubber concrete showed localized voids and weaker bonding at the rubber–cement interface due to the hydrophobic nature of rubber particles. Nevertheless, the incorporation of steel fibres improved crack-bridging behaviour and enhanced the compactness of the cement matrix. The microstructural observations correlated well with the experimentally observed mechanical behaviour, indicating that optimized crumb rubber concrete can provide improved ductility while maintaining satisfactory structural performance. The study demonstrates the significance of SEM analysis in understanding the internal behaviour of sustainable concrete materials.**

Index Terms—**Crumb Rubber Concrete, Scanning Electron Microscope, Microstructure, Steel Fibre, Hydration Products, Sustainable Concrete.**

I. INTRODUCTION

The increasing accumulation of discarded automobile tyres has become a significant environmental concern worldwide. Since rubber is a non-biodegradable material, conventional disposal methods such as landfilling and open burning create serious environmental and health hazards. Consequently, researchers have explored the utilization of waste tyre rubber in concrete as a sustainable alternative for reducing environmental pollution while conserving natural aggregate resources. Rubberized concrete has therefore emerged as an eco-friendly construction material capable of promoting circular economy principles within the construction industry.

Crumb rubber concrete is produced by partially replacing natural fine or coarse aggregates with processed waste tyre rubber particles. The incorporation of crumb rubber generally reduces the density and stiffness of concrete while enhancing its ductility, impact resistance, vibration damping, and energy absorption capacity. However, due to the elastic nature and hydrophobic surface of rubber particles, a reduction in compressive strength is commonly observed because of weaker bonding within the cement matrix. These changes in mechanical behaviour are primarily governed by the internal microstructure of the material.

Microstructural characterization provides valuable insight into the mechanisms responsible for the behaviour of modified concrete. Among the available characterization techniques, Scanning Electron Microscopy (SEM) is one of the most effective tools for investigating the morphology of cementitious materials. SEM enables detailed examination of hydration products such as calcium silicate hydrate (C–S–H), calcium hydroxide (CH), ettringite, pore distribution, microcracks, and the interfacial transition zone (ITZ) between aggregates and cement paste. These observations assist in correlating microscopic features with the macroscopic mechanical performance of concrete.

Previous studies have primarily focused on evaluating the compressive, tensile, and flexural strengths of crumb rubber concrete. Although these investigations provide useful information regarding structural performance, comparatively fewer studies have emphasized understanding the microstructural changes responsible for these behaviours, particularly for concrete incorporating crumb rubber and steel fibres simultaneously. Therefore, a detailed SEM investigation becomes essential for understanding the influence of rubber particles on hydration characteristics, pore formation, and bond development within the concrete matrix.

The present study investigates the microstructure of M30 grade crumb rubber concrete through SEM analysis. The research aims to compare the morphology of conventional concrete and crumb rubber concrete by examining hydration products, pore structure, microcracks, and aggregate–paste bonding. The observations obtained from SEM analysis are further correlated with the experimentally observed mechanical behaviour to explain the performance of crumb rubber concrete at the microscopic level.

II. LITERATURE REVIEW

1) Ganjian et al. (2009) investigated concrete containing discarded tyre rubber at replacement levels of 5%, 7.5%, and 10%. Their study reported that replacement levels up to 5% produced only minor reductions in mechanical properties while maintaining acceptable durability. The authors concluded that limited crumb rubber incorporation provides an effective solution for recycling waste tyres without significantly affecting concrete performance.

2) Nileshwari Nagarkar (2019), examines crumb rubber as a partial replacement for fine aggregates in concrete and integrates glass fibres to enhance strength development. Various crumb rubber percentages were analysed for compressive, flexural, and tensile strength. The findings show that rubberized concrete improves ductility and fracture resistance, despite a reduction in compressive strength—partially mitigated by glass fibre reinforcement. The study supports the use of crumb rubber as an eco-friendly alternative for concrete production, addressing waste tyre management and natural aggregate depletion.

3) Abraham Bebe Barmoh et al. (2023) investigated sodium hydroxide-treated crumb rubber as a partial replacement for fine aggregate in high-strength concrete. Surface treatment significantly improved the bond between rubber particles and cement paste, resulting in better compressive, tensile, and flexural strengths compared with untreated rubber concrete. Their work demonstrated that improving the rubber–cement interface is crucial for enhancing the overall performance of crumb rubber concrete.

4) Wang et al. (2025) reported that the incorporation of steel fibres within cementitious composites considerably improved crack control, ductility, and load-carrying capacity by enhancing the internal load transfer mechanism. Their findings emphasized the role of fibres in delaying crack propagation and improving the overall integrity of the cement matrix.

Recent developments in SEM-based concrete research have demonstrated that the morphology of hydration products, pore distribution, and interfacial transition zones directly influence the mechanical performance of concrete. Dense C–S–H gel formation and reduced pore connectivity generally result in improved compressive strength, whereas weak aggregate–paste interfaces and increased porosity lead to premature crack initiation. Consequently, SEM has become an indispensable technique for evaluating the microstructural characteristics of sustainable concrete materials and explaining their engineering behaviour.

The above studies indicate that although considerable research has been conducted on the mechanical behaviour of crumb rubber concrete, comparatively fewer investigations focus specifically on its microstructural characteristics using SEM. Therefore, the present work aims to examine the microstructure of crumb rubber concrete and correlate the observed hydration products, pore structure, and interfacial bonding with its overall engineering performance.

III. METHODOLOGY

Representative concrete specimens were selected after the completion of the curing period for microstructural examination. Small fragments were carefully extracted from the interior of the specimens to avoid surface contamination and to expose the actual internal microstructure. The extracted samples were oven-dried at approximately 60°C for 24 hours to remove residual moisture. The dried specimens were then mounted on aluminium stubs using conductive carbon tape. To improve electrical conductivity and eliminate charging effects during imaging, the specimen surfaces were sputter-coated with a thin layer of gold prior to microscopic examination.

Scanning Electron Microscopy (SEM) was employed to examine the microstructural characteristics of crumb rubber concrete. In this technique, a focused beam of high-energy electrons was directed onto the specimen surface under high vacuum conditions. The interaction between the incident electron beam and the specimen generated secondary and backscattered electrons, which were detected to produce high-resolution images of the concrete microstructure. SEM images were captured at suitable magnifications to examine the morphology of hydration products and the internal structure of the cement matrix.

The obtained SEM micrographs were analyzed to evaluate the morphology of the cementitious matrix, hydration products, pore distribution, and the interfacial transition zone (ITZ) between crumb rubber particles and the surrounding cement paste. Particular attention was given to the identification of calcium silicate hydrate (C–S–H) gel, calcium hydroxide (CH) crystals, ettringite formations, micro voids, and microcracks. The microstructural features observed in conventional concrete and crumb rubber concrete were compared to assess the influence of crumb rubber incorporation on the internal morphology. The SEM observations were further correlated with the experimentally observed mechanical behaviour to explain the influence of the microstructure on the engineering performance of the concrete.

- CC – Conventional Concrete
- CRCA+SF – Concrete containing 5% crumb rubber as partial coarse aggregate replacement and 1% steel fibre

IV. RESULTS AND DISCUSSION

Scanning Electron Microscopy (SEM) was performed to evaluate the microstructural characteristics of conventional concrete and crumb rubber concrete. The micrographs were analysed to identify hydration products, pore distribution, interfacial transition zone (ITZ), and microstructural defects resulting from the incorporation of crumb rubber.

The SEM analysis of conventional concrete revealed a dense and compact cement matrix with well-developed calcium silicate hydrate (C–S–H) gel, indicating effective cement hydration. Calcium hydroxide (CH) crystals were uniformly distributed within the matrix, while the interfacial transition zone (ITZ) between the aggregate and cement paste appeared dense with minimal microvoids. The compact microstructure contributed to efficient stress transfer and enhanced mechanical performance.

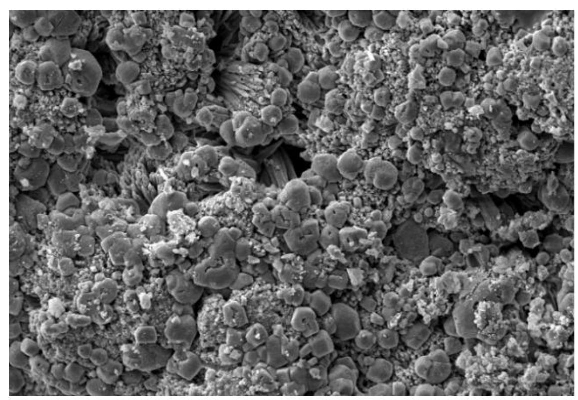

Fig - 01: SEM image of Conventional Concrete

The SEM analysis of crumb rubber concrete showed the presence of rubber particles embedded within the cement matrix. Localized voids were observed around the rubber particles due to their hydrophobic surface characteristics, resulting in a comparatively weaker interfacial bond than conventional concrete. However, the cement matrix exhibited continuous C–S–H gel formation, indicating adequate hydration. The incorporation of steel fibres effectively restricted the propagation of microcracks through crack-bridging action, thereby improving the integrity of the concrete matrix.

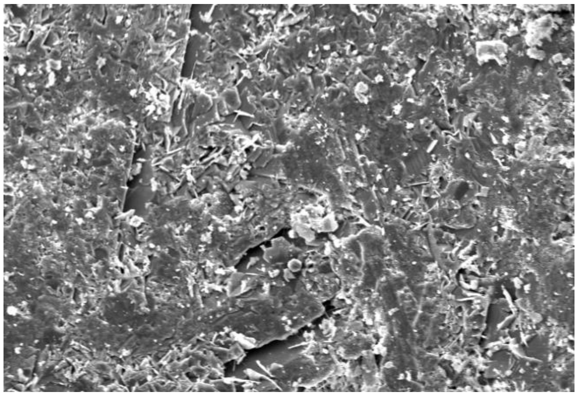

Fig – 02: SEM image of CRCA + SF

The SEM observations demonstrated that the inclusion of crumb rubber altered the internal morphology of concrete by increasing localized porosity and modifying the aggregate–paste interface. Despite these changes, the development of hydration products and the crack-bridging effect of steel fibres contributed to maintaining the structural integrity of the composite. The microstructural observations are consistent with the experimental findings, where crumb rubber concrete exhibited improved ductility and satisfactory mechanical performance while promoting the sustainable utilization of waste tyre rubber.

V. CONCLUSION

This study presented a microstructural evaluation of crumb rubber concrete using Scanning Electron Microscopy (SEM) to understand the influence of crumb rubber on the internal morphology of the cementitious matrix. Based on the experimental observations, the following conclusions are drawn:

1) SEM analysis confirmed the formation of hydration products, primarily calcium silicate hydrate (C–S–H) gel and calcium hydroxide (CH) crystals, indicating adequate cement hydration in both conventional and crumb rubber concrete.
2) The incorporation of crumb rubber introduced localized pores and a comparatively weaker interfacial transition zone (ITZ) due to the hydrophobic nature of rubber particles, resulting in increased microstructural discontinuities.
3) The addition of steel fibres enhanced crack-bridging behaviour and improved the integrity of the cement matrix by restricting the propagation of microcracks.
4) The microstructural observations correlated well with the experimentally observed mechanical behaviour, demonstrating that the internal morphology significantly influences the performance of crumb rubber concrete.
5) The findings suggest that crumb rubber concrete can be considered a sustainable construction material, offering an effective solution for recycling waste tyres while maintaining satisfactory engineering performance.

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