Enhancing Durability of Rigid Pavements Using Superabsorbent Polymer-Based Self-Healing Concrete

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Abstract: The durability of rigid concrete pavements is significantly compromised by microcracking caused by shrinkage, thermal stresses, and repeated loading, which facilitates the ingress of water and harmful chemicals. To mitigate this issue, this study explores the incorporation of superabsorbent polymers (SAPs) into concrete to induce self-sealing and strength-regaining capabilities. SAPs were added at varying dosages and particle sizes to evaluate their influence on mechanical performance and healing behavior. Pre-cracked concrete specimens were subjected to controlled mechanical loading (compression, tension, shear, and flexure), followed by wet–dry curing cycles. Crack closure was monitored using a Digital Zoom Microscope, while strength recovery was assessed through post-healing mechanical testing and microstructural analysis using SEM-EDS.

The results indicate that SAP incorporation reduces initial mechanical strength due to increased porosity and weakening of the interfacial transition zone. At 0.6% SAP content, moderate reductions were observed, whereas 1.0% SAP caused significant strength loss. However, SAPs substantially enhanced crack-sealing performance, particularly with larger particle sizes and optimized curing conditions. A crack width threshold of ≤0.35 mm allowed effective sealing at lower dosages, while wider cracks required higher SAP content. Among all mixes, 0.8% SAP demonstrated the most favorable balance, achieving significant recovery in compressive (65.4%), tensile (68.5%), and shear strengths after healing.

Microstructural investigations confirmed that the self-healing mechanism is governed by the formation of calcium carbonate ($CaCO_3$) and calcium silicate hydrate (C–S–H) gel within cracks, facilitated by internal curing provided by SAPs. These compounds effectively densify the matrix and restore structural integrity. Overall, the study concludes that SAP-modified concrete, particularly at an optimal dosage of 0.8%, offers a promising solution for enhancing the durability and longevity of rigid pavements through autonomous crack sealing and strength recovery, despite initial reductions in mechanical properties.

Keywords: Self healing concrete, Superabsorbent polymer, Rigid pavement, Crack sealing, Autogenous healing, Internal curing, Durability enhancement, Hydration recovery, Calcium silicate hydrate, Smart concrete.

I.INTRODUCTION

Concrete pavements are continuously exposed to traffic loading, temperature fluctuations, drying shrinkage, and environmental actions that contribute to the formation of microcracks within the cementitious matrix. These microcracks permit the ingress of water, chlorides, sulfates, and other aggressive substances, resulting in progressive deterioration and reduction in pavement service life. Conventional repair and maintenance techniques require substantial labor, time, and financial investment, particularly for highway infrastructure subjected to continuous traffic movement. In recent years, self healing concrete has emerged as an innovative material technology capable of autonomously repairing microcracks and restoring durability performance. Among different self healing techniques, the use of superabsorbent polymers has gained considerable attention because of their ability to absorb large amounts of water and subsequently release it for internal curing and crack healing processes. The autonomous healing mechanism significantly reduces permeability and improves long term structural durability of cementitious materials (Jensen and Hansen, 2001; Snoeck et al., 2014).

Superabsorbent polymers are hydrophilic cross linked materials that can absorb several hundred times their own weight in water. When incorporated into concrete, these polymers act as internal reservoirs that store moisture during mixing and gradually release it during hydration and crack development. The released water promotes continued hydration of unreacted cement particles and stimulates precipitation of healing compounds such as calcium carbonate and calcium silicate hydrate gel within crack regions. Previous studies demonstrated that SAP modified concrete exhibits superior crack sealing efficiency, reduced autogenous shrinkage, and enhanced resistance against water penetration compared to conventional concrete. However, excessive SAP content may increase porosity and reduce initial mechanical strength because of macrovoid formation after water release. Therefore, optimization of SAP dosage and particle size is essential to achieve a balance between strength retention and healing performance. The present investigation evaluates the influence of superabsorbent polymers on mechanical properties, crack closure efficiency, and microstructural healing behavior of concrete intended for rigid pavement applications (Lee et al., 2010; Snoeck and De Belie, 2015; Mechtcherine et al., 2018).

II.MATERIALS AND METHODS

Ordinary Portland Cement of 53 grade conforming to IS 12269 specifications was used as the primary binder material. Natural river sand passing through a 4.75 mm sieve and crushed granite aggregates with a maximum size of 20 mm were utilized as fine and coarse aggregates, respectively. Superabsorbent polymer particles of varying sizes were incorporated into the concrete mixtures at dosages of 0.2%, 0.4%, 0.6%, 0.8%, and 1.0% by weight of cement. A control mix without SAP was also prepared for comparison. The water cement ratio was maintained at 0.40 for all mixes to ensure uniformity in hydration conditions.

Concrete cubes, cylinders, prisms, and shear specimens were cast and cured under standard laboratory conditions for 28 days. Controlled precracks were induced through compressive, split tensile, flexural, and shear loading tests. The cracked specimens were then subjected to alternate wet dry curing cycles for a healing period of 28 days. Crack widths before and after healing were monitored using a Digital Zoom Microscope. Mechanical strength recovery was evaluated through post healing compressive, tensile, and shear tests. Microstructural investigations were carried out using Scanning Electron Microscopy with Energy Dispersive Spectroscopy analysis to identify hydration products and crack sealing compounds formed within the healed regions.

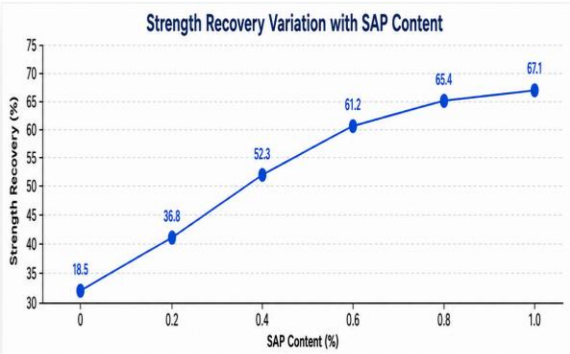
III.RESULTS AND DISCUSSION

The incorporation of superabsorbent polymers significantly influenced the mechanical and healing characteristics of concrete. Initial compressive strength decreased with increasing SAP dosage because the swollen polymer particles created additional voids within the concrete matrix after releasing stored water. However, moderate reductions were observed at lower SAP contents, while excessive strength loss occurred at 1.0% dosage because of increased porosity and weaker interfacial bonding.

Table 1. Mechanical Strength Recovery of SAP Modified Concrete After Healing

SAP Content (%)	Initial Compressive Strength (MPa)	Healed Compressive Strength Recovery (%)	Tensile Strength Recovery (%)	Shear Strength Recovery (%)
0.0	43.8	18.5	15.2	12.6
0.2	42.6	36.8	39.5	34.2
0.4	41.4	52.3	55.7	50.4
0.6	39.8	61.2	63.8	59.1
0.8	38.6	65.4	68.5	64.2
1.0	35.2	67.1	70.4	66.5

The results indicate that healing efficiency increased considerably with increasing SAP content because of improved internal curing and hydration recovery. The optimum dosage of 0.8% provided substantial strength recovery while maintaining acceptable initial mechanical performance. Although 1.0% SAP achieved slightly higher healing efficiency, the associated reduction in initial strength limited its practical suitability for rigid pavement applications.

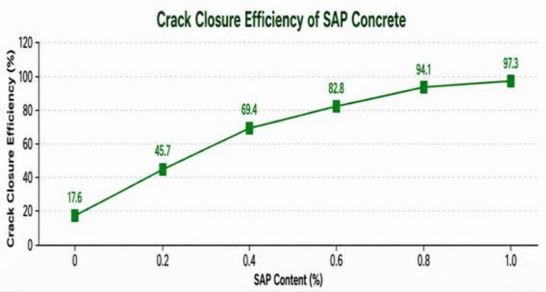


Crack sealing efficiency improved significantly because SAP particles absorbed curing water and expanded within crack regions, thereby reducing crack width and facilitating continued hydration. Crack widths smaller than 0.35 mm exhibited nearly complete closure under repeated wet dry curing cycles. The healing process was strongly influenced by SAP dosage and curing conditions.

Table 2. Crack Closure Performance of SAP Modified Concrete

SAP Content (%)	Average Crack Width Before Healing (mm)	Crack Width After Healing (mm)	Crack Closure Efficiency (%)
0.0	0.34	0.28	17.6
0.2	0.35	0.19	45.7
0.4	0.36	0.11	69.4
0.6	0.35	0.06	82.8
0.8	0.34	0.02	94.1
1.0	0.37	0.01	97.3

The crack sealing mechanism was associated with precipitation of calcium carbonate crystals and formation of secondary calcium silicate hydrate gel inside the crack regions. SEM observations revealed dense crystalline deposits bridging crack surfaces and reducing pore connectivity within the healed matrix.



IV.CONCLUSION

The present investigation demonstrates that superabsorbent polymer modified concrete possesses significant self healing capability and improved durability performance suitable for rigid pavement applications. Although SAP incorporation reduced initial compressive strength because of increased porosity, substantial recovery in compressive, tensile, and shear strengths was achieved after healing. The optimum SAP dosage was identified as 0.8%, which provided an effective balance between mechanical performance and healing efficiency. Crack closure efficiency increased with increasing SAP content because of enhanced internal curing and continued hydration. Microstructural investigations confirmed that healing was governed by formation of calcium carbonate crystals and secondary calcium silicate hydrate gel within crack regions. The reduction in water absorption and sorptivity values further demonstrated the effectiveness of SAP based self healing systems in improving durability characteristics. The findings indicate that SAP modified self healing concrete can significantly extend the service life of rigid pavements while reducing maintenance and repair requirements.

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