

Study of Properties and Self-Healing Phenomenon of Sleeve Grout

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ABSTRACT

Like the human body, cement composites possess a "self-healing" ability that enables them to repair damage, providing structures with a level of self-sufficiency. One key application of this is the precast grouted sleeve connection—comprising a cement composite encased in steel—that securely joins precast elements into a monolithic structure. This study presents a newly developed grout, comparing its mechanical properties and self-healing performance against a research grout (W) and a commercial grout (C). The study explores various healing mechanisms, including autogenic self-healing, bacteria-based methods, mineral admixtures, polymeric adhesives, superabsorbent polymers, and shape-memory materials. It also reviews reliable techniques for assessing healing efficiency, such as mechanical testing, microscopy, spectroscopy, thermal analysis, and imaging, to characterize healing products, microstructures, and processes. Additionally, the challenges and limitations of self-healing materials and encapsulation methods are addressed, along with insights into future advancements in self-healing cementitious materials. The paper concludes with a case study on four self-healing systems, showcasing their practical applications and effectiveness

I. INTRODUCTION

This research discusses the concept of self-healing in cement composite structures, highlighting its significance as a mechanism to repair without external intervention. In this study, 33 grout specimens were prepared and divided into three groups: research grout (W), commercial grout with 10% expansion agent (CCSA), and research grout with an expansion agent (WCSA). The specimens were mixed in a laboratory using cement, CSA, and water, ensuring a homogeneous mixture. Molds were cleaned and oiled before the grout was cast in two layers, with each layer vibrated for 120 seconds. After casting, the specimens were covered to maintain moisture for 24 hours and then cured at room temperature for 28 days. Following curing, the specimens were subjected to compression and flexure testing to initiate cracks by loading them to 75% of their ultimate strength. The grout was then further cured in tap water and saturated $\text{Ca}(\text{OH})_2$ solution for 20 and 35 days, and tested for self-healing efficiency using compression, ultrasonic pulse velocity, sleeve tensile testing, and SEM analysis.

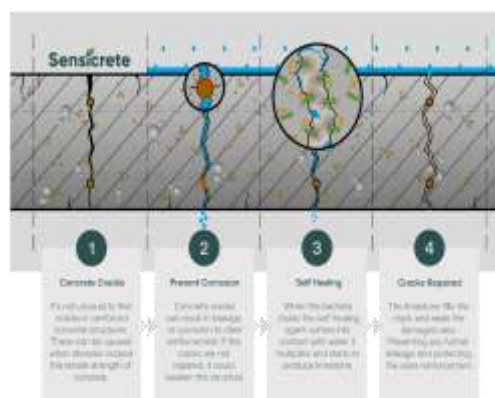


FIG 1 :[R]GOOGLE PICTURES

II. LITERATURE REVIEW

2.1 PRECAST GROUT SLEEVES

The structural behaviour of precast concrete frames is fundamentally governed by the connections between their components. Effective design of these connections is critical for successful precast construction. Connections can generally be categorized into two types: dry connections and wet connections. In dry connections, members are joined using steel plates or other components, which are then welded or bolted together. In contrast, wet connections utilize grout or cast-in-place concrete to bond the members. Grouted sleeve joints, a type of wet connection, are

commonly employed in precast concrete structures, as illustrated in Fig 2

The concept of using non-proprietary pipes for splicing steel bars was first introduced by Eine et al.

[1] in 1995. Kim [2] later adopted this approach, applying pipe sections for beam-column connections.

Since then, researchers have explored various non-proprietary materials for grouted splices, including mild steel pipes [3–7], spirals [8], square hollow sections [9], corrugated aluminium sleeves [10], and glass fibre reinforced polymers [11–14]. These non-proprietary splices, known as grouted splices, consist of a sleeve, grout, and two spliced bars, representing a type of mechanical splice.

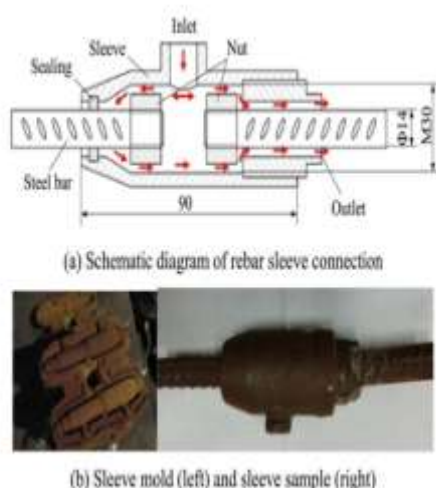


FIG 2: [R] JULE LUSHUMO [1]

The materials used in grout include commercial Portland cement, research cement, CSA-based expansion agents, water, and various additives. Portland cement, made primarily from limestone and clay, is the most common binder in grout, mortar, and concrete, and its composition includes compounds like tricalcium silicate (C3S) and dicalcium silicate (C2S), which control setting and hardening rates. Research cement, developed with additives like silica fume, nano-silica, and polycarboxylic acid, enhances strength and ductility for specialized applications, such as grouted sleeve connections. CSA-based expansion agents, which include compounds like belite and ye'elimite, are used to create expansive cement with properties like shrinkage compensation and

rapid setting. Distilled water is used in mixing, while specimens may be cured in tap or saturated lime water to promote self-healing reactions in CSA. The study also utilizes threaded half-sleeve connections to join rebars in precast concrete structures

2.2 ADVANCES IN SELF-HEALING STRATEGIES

The literature review shows that several different materials can be used to improve the self-healing efficiency of cracked cementitious materials. Self-healing can be broadly classified into the following categories

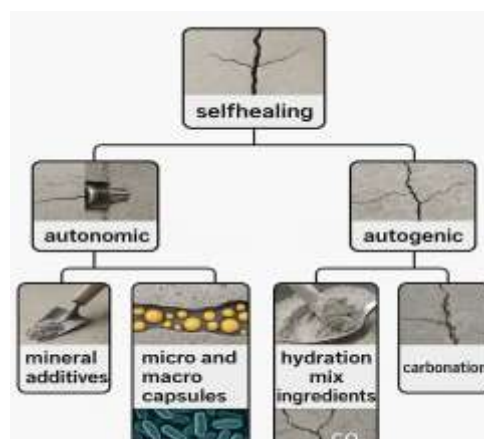


FIG 2: SELF HEALING CATEGORIES[12]

2.2.1 Autogenic self-healing & Autonomic Self-healing

Autogenic self-healing in cementitious materials occurs through physical, chemical, and mechanical processes, including the swelling of the cement matrix, rehydration of unhydrated particles, calcium carbonate formation, and the deposition of fine particles. However, its efficiency is often low, especially in older concrete, due to reduced portlandite and moisture availability. Autonomic self-healing, inspired by biological systems, refers to systems that automatically detect and repair faults without human intervention. In computing and network management, this concept enhances system reliability by proactively addressing issues through algorithms and machine learning. Both forms of self-healing contribute to more resilient materials and infrastructures, reducing the need for manual maintenance.

III. LABORATORIES FINDING ON SELF-HEALING MECHANISMS IN CONCRETE COMPRESSION TEST RESULTS

Table 1: COMPRESSION TEST RESULTS FOR COMMERCIAL GROUT

Age	specimen	Flexural strength	Average Strength (MPa)	Compression Strength	Average strength (MPa)
3-d	W3-1	6.26	7.43	45.255	43.777
	W3-2	7.76			
	W3-3	8.28		42.298	
7-d	W7-1		10.48	52.974	51.504
	W7-2	10.38		50.637	
	W7-3	10.58		50.901	
14-d	W14-1	12.04	12.40	65.632	64.816
	W14-2	16.48		64.000	
	W14-3	12.76		53.326	
28-d	W28-1	10.52	10.34	80.327	81.473
	W28-2	10.47		66.606	
	W28-3	10.04		82.709	

Compression

The above are for lab tests carried out on specimen of self-healing concrete. The specimen compressive strength was 44.59MPa for the commercial grout and an average of 43.777 for the research grout. Specimen W3-2 was discarded due to errors during the testing. Although the W3-1 has a slightly higher compressive strength than C3-1, specimen W3-3 has a lower compressive strength than specimen C3-1 construction.

trend suggests that the material gains strength over time, with an optimal performance at 14 days before stabilizing or slightly declining.

Flexural

The flexural strength results in the graph indicate that both Sample 1 (blue) and Sample 2 (orange) increase in strength over time, peaking at 14 days before slightly decreasing at 21 days. At 3 days, both samples have nearly identical values, around 8. By 7 days, both samples increase to approximately 10, showing a steady gain in strength. At 14 days, Sample 2 surpasses Sample 1 slightly, reaching the highest recorded strength of about 12. However, by 21 days, both samples experience a slight reduction in strength, settling at similar values just below the 14-day peak. This



FIG2. COMPRESSION MACHINE

SELF HEALING EFFICIENCY

Different specimen we cured under different conditions and the self-healing efficiency was calculated below are the results I will observe, and I will evaluate self-healing of 20 days and that of 35 days . the curing time of each specimen is written at the end of the specimen's name

TABLE 2 : SELF HEALING EFFICIENCY %

	W-1	CCSA-1	WCOSA-1
Water 20d. Ca(OH)	70.5%	132.6%	146.0%
Water 35d Ca(OH)	75.5%	117.0%	100.0%
	80.6%	126.0%	122.0%
	99.7%	100.0%	134.8%

The self-healing efficiency of grout specimens varied significantly depending on the curing environment. WCCSA in Ca(OH)₂ and WWCSA-1 in water were the most efficient in their

respective conditions, with WWCSA-1 showing a marked increase in self-healing over time. In contrast, CWCSA-1 exhibited moderate healing but plateaued after 20 days, while WW-1 had the

lowest healing efficiency in water, making it the least suitable for self-repair in that environment. These results underscore the importance of material selection and curing conditions, as different

specimens respond differently to their exposure environments.

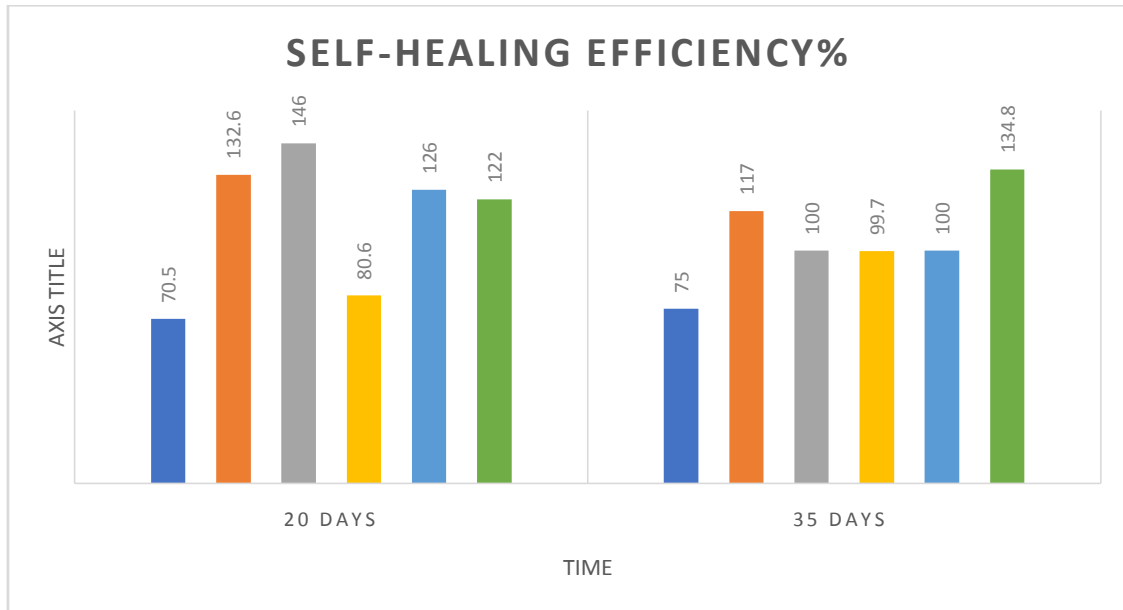


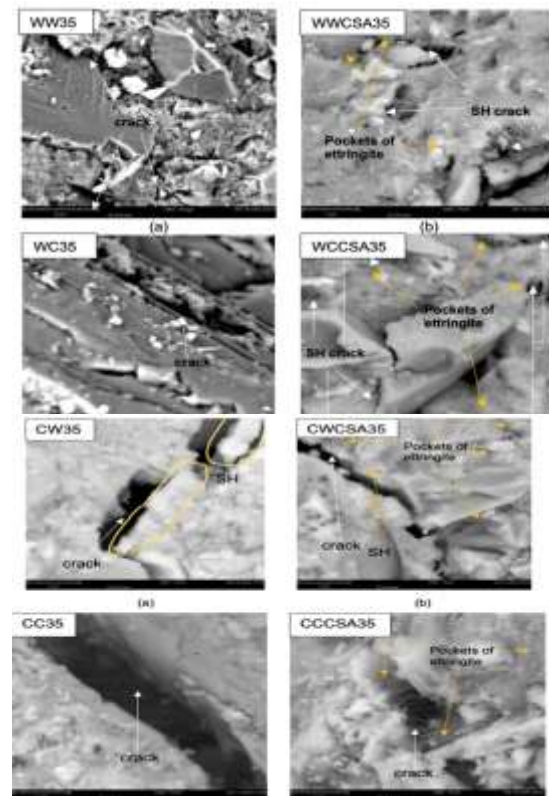
FIG 3 EFFICIENCY GRAPH

This graph compares the self-healing efficiency of specimens cured in water and $\text{Ca}(\text{OH})_2$ across three different rankings: 1st Best, 2nd Best, and 3rd Best. Initially, the specimens cured in water show a higher healing efficiency (99.7%) compared to those in $\text{Ca}(\text{OH})_2$ (75%) for the 1st Best category. However, for the 2nd Best, $\text{Ca}(\text{OH})_2$ curing reaches its peak efficiency at 117%, slightly surpassing water at 100%. In the 3rd Best category, the trend reverses again, with water curing achieving the highest efficiency at 124.8%, while $\text{Ca}(\text{OH})_2$ drops to 100.6%. Based on this data, water curing consistently provides higher self-healing efficiency, especially in the best-performing and third-best categories, making it the more effective option for curing samples.

images makes it an essential tool for quality control, research, and failure analysis.

SEM ANALYSIS

Scanning Electron Microscopy (SEM) analysis is a technique used to examine the surface morphology and composition of materials at a high magnification and resolution. It works by directing a focused beam of electrons onto a sample, which interacts with the material to produce detailed images and elemental data. SEM is widely used in materials science, engineering, biology, and forensic investigations to study surface structures, detect defects, and analyse chemical compositions. Its ability to generate three-dimensional-like



A total of 8 samples were analysed by SEM: 4 of the research grouts and 4 of the commercial grouts. One of each specimen was cured in water and in saturated lime water. The SEM analysis of WW35 and WC35 specimens, pre-cracked at 28 days and cured for 35 days, shows self-healing in the C-S-H matrix. WW35 exhibited minor self-healing along crack edges, while WC35 had more prominent hydration products, likely due to excess Ca^{2+} ions in saturated lime water. Water infiltration facilitated further cement hydration, promoting self-healing, especially in WC35.

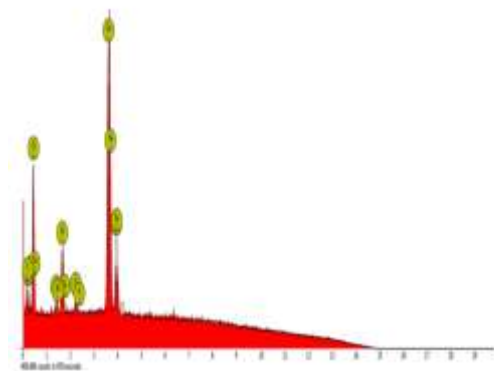


FIG 5: SEM TESTS

The SEM-EDS spectrum indicates a high presence of calcium silicon, and oxygen, suggesting cement hydration products like C-S-H. Aluminium and sulphur point to aluminosilicates or sulphates, while iron and carbon may stem from impurities or additives. The elemental composition aligns with cementitious materials, supporting hydration and potential self-healing mechanisms. The SEM results showed that the specimen with CSA underwent self-healing due to the hydration of the grout and the production of ettringite, whereas the specimen without CSA primarily had hydration products as their self-healing products. The specimen cured in saturated lime water with CSA included had much more ettringite which led to not only the reduction in crack width, but also bridging of cracks.

IV. SUMMARY

This paper explores the development and assessment of self-healing grout used in precast grouted sleeve connections, focusing on materials and methods that enhance the grout's ability to self-repair. The study evaluates traditional Portland cement alongside a research grout formulation incorporating additives like silica fume, nano-silica, and a CSA-based expansive agent (DENKA HP-CSA). These materials promote the formation of

ettringite, which aids in sealing cracks. Curing methods, including the use of tap water and saturated lime water, are examined to determine their impact on self-healing efficiency. The research compares two self-healing mechanisms: autogenic self-healing, which relies on the continued hydration of unreacted cement, and autonomic self-healing, triggered by the added expansive agent. Mechanical recovery tests assess the grout's strength regain after damage, aiming to determine the practical effectiveness of self-healing in construction applications. The paper also highlights challenges, such as ensuring uniform crack closure and integrating self-healing properties without compromising structural integrity. Overall, the research provides insights into enhancing durability and sustainability in precast concrete structures.

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