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Experimental Investigation on Permeability control in Contact Grouting Using Crystalline Admixture for Tunneling Application

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ABSTRACT
This study investigates the effectiveness of crystalline waterproofing admixture MB LIFE WP760 in controlling permeability and improving performance of contact grouting materials for tunneling applications. Contact grouting plays a crucial role in reducing water ingress, filling voids between the lining and surrounding ground, and enhancing structural stability. However, conventional grout mixes often face limitations such as inadequate permeability resistance and variable strength development. In this research, grout samples incorporating 0.8% MB LIFE WP760& 1% Mudrock Chemi flow 100 were evaluated against control mixes to assess improvements in fresh and hardened properties. Key parameters such as viscosity, density, setting time, bleeding, compressive strength, and water penetration were studied in accordance with relevant IS standards. Results indicate that the admixture maintains desirable workability, with only marginal variations in viscosity and setting time. The modified grout exhibits slightly higher early and long-term compressive strength compared to the control mix. The findings confirm that MB LIFE WP760 enhances durability and impermeability of grout mixes without compromising mechanical performance. The study concludes that incorporating crystalline admixtures in contact grouting presents a promising approach for improving waterproofing efficiency and long-term stability in tunnel construction.

Keywords: Grouting; Permeability; Quality assurance; tunnel

I. INTRODUCTION

Concrete is one of the most widely used construction materials due to its versatility, durability, and cost- effectiveness. However, its performance may frequently be hindered by permeability issues that enable the infiltration of water and other liquids, ultimately undermining the durability and structural integrity of concrete structures. Also, improving the impermeability of concrete while keeping or increasing its compressive strength is very important. One promising solution involves the use of crystalline admixtures in concrete. Applied during mixing, these admixtures react with cement hydration byproducts to form insoluble crystalline structures within the concrete matrix, effectively fillingpores and reducing permeability. Furthermore, crystalline admixtures have shown to enhance compressive strength across various applications. The development and application of crystalline admixture technologies have significantly advanced overtime. Initially, the primary concern in concrete construction was addressing wateringress, a pervasive issue that often led to structural deterioration, reinforcement corrosion, and costly repairs. Concrete, by its nature, is a porous material, which allows water and other harmful substances to infiltrate its structure, compromising its integrity and longevity [1].

In the early stages, researchers and engineers focused on identify-ing chemical compounds that could react with water within the concrete matrix to form crystalline structures. These compounds, often based on specific types of silicates, were designed to react with the byproducts of cement hydration, particularly calcium hydroxide. The reaction would result in the formation of insoluble, needle-like crystals that could grow within the micro-cracks and capillary pores of the concrete, effectively sealing them and preventing further water ingress. As research in materials science and chemistry advanced, the formulations of crystalline admixtures were refined [2-3].

Scientists gained a better understanding of the crystallization process and how it could be optimized to enhance concrete's properties. This led to the development of more so-phisticated admixtures that not only improved impermeability but also enhanced other critical properties of concrete, such as the compressive strength and durability. These advancements made crystalline admixtures more reliable and efficient, leading to their widespread acceptance in the construction industry.

Crystalline admix-tures proved especially valuable in projects subjected to harsh weather conditions or underground constructions. The ability of these admixtures to provide long-term protection against water damage and chemical attack made them a standard component in many concrete formulations. Furthermore, the application techniques for crys- talline admixtures evolved. Initially, these admixtures were primarily used in new concrete constructions, which were mixed into the concrete during batching [4].

II. CRYSTALLINE ADMIXTURE FOR TUNNELING APPLICATION

Crystalline admixtures (CA) are advanced waterproofing materials increasingly used in tunneling applications to enhance the durability and impermeability of concrete and grout systems. These admixtures contain reactive chemicals that, when mixed with cement and exposed to moisture, form insoluble crystalline structures within the pore network and microcracks of the concrete or grout matrix [5]. In tunneling, where structures are constantly exposed to high hydrostatic pressure and groundwater seepage, the use of crystalline admixtures provides a self-sealing mechanism that significantly reduces water permeability and prevents leakage. Moreover, the crystalline growth continues to develop over time in the presence of moisture, offering long-term protection and resistance to chemical attack. This self-healing property makes crystalline admixtures a sustainable and low- maintenance solution for waterproofing tunnel linings, contact grouting, and underground structural elements, ensuring enhanced service life and structural integrity under harsh underground conditions.

III. RESEARCH MOTIVATION

Crystalline admixtures proved especially valuable in projects subjected to harsh weather conditions or underground constructions. The ability of these admixtures to provide long-term protection against water damage and chemical attack made them a standard component in many concrete formulations. Furthermore, the application techniques for crystalline admixtures evolved. Initially, these admixtures were primarily used in new concrete constructions, which were mixed into the concrete during batching. However, as the technology progressed, they were also developed for use in existing structures as surface-applied treatments [6].

IV. PROBLEM IDENTIFICATION

In tunneling projects, controlling permeability around the tunnel lining is a critical challenge, especially in weak, fractured, or water-bearing ground conditions. Conventional cement-based contact grouting often fails to achieve the desired impermeability due to limitations such as high bleeding, poor penetration into fine voids, and inconsistent sealing performance under varying geological stresses. As a result, water ingress continues to pose risks like reduced structural durability, increased maintenance costs, and safety concerns during tunnel operation. Crystalline admixtures—known for their ability to chemically react with moisture and form insoluble crystals— offer potential for enhanced permeability reduction, but their performance in contact grouting applications remains inadequately understood. Therefore, a systematic experimental investigation is required to evaluate how crystalline admixtures influence grout permeability, setting characteristics, and long-term sealing efficiency in tunneling environments [7].

V. MATERIALS USED

1. Cement

- Type: Ordinary Portland Cement (OPC), 53 grade.
- Standard: IS -12269 .
- Purpose: Main binding material for grout formation.

2. Water

- Type: Clean, potable water free from organic matter and salts.
- Water-Cement Ratio (w/c)
- Typically constant 0.45 across all mixes for consistenc.
- Purpose: Reacts with cement to form a paste, helps achieve workable grout.

3.

I) Admixtures (Main experimental variable)-To reduce water permeability

II) Admixtures-1% (Mudrock Chemiflow 100)-To improve workability

PVC MEMBRANE

A PVC membrane is a flexible, durable, and fully waterproof synthetic sheet made from polyvinyl chloride, commonly used as a primary waterproofing barrier in tunnels, basements, water tanks, subways, and other underground structures. It is installed outside or around the concrete lining to prevent groundwater, seepage, or leakage from entering the structure. Due to its high elasticity, chemical resistance, and long-term stability, a PVC membrane provides effective protection against water pressure and environmental exposure. In tunneling applications, it forms a continuous waterproof layer that works in combination with contact grouting and crystalline admixtures to ensure a reliable and long- lasting waterproofing system.

Table 1. Test Results and Conformity (As per IS 15909:2020, Type VI)-1.

S. No.	Requirement / Name of Test	Unit	Result	Specification (IS 15909:2020 Type VI)	Conformity	Test Method
1.	Total Thickness at 20 kPa	mm	2.16	2 +10% / -0%	Yes	IS 13162 (Part 3), Method A
2.	Specific Gravity	—	1.297	1.30 ± 0.03	Yes	IS 2076 (Method A)
3.	Tensile Strength					
	a. Longitudinal Direction	N/mm²	22.3	17 Min.	Yes	IS 15909
	b. Transverse Direction	N/mm²	20.0	17 Min.	Yes	
4.	Elongation at Break					
	a. Longitudinal Direction	%	347	325 Min.	Yes	IS 15909
	b. Transverse Direction	%	368	325 Min.	Yes	
5.	Tear Propagation Strength					
	a. Longitudinal	N/mm	132.9	100 Min.	Yes	IS 15909
	b. Transverse	N/mm	122.2	100 Min.	Yes	

Table 2. Test Results and Conformity (As per IS 15909:2020, Type VI)-2.

S. No.	Name of Test	Unit	Result	Requirement (IS 15909-2020) (Type VI)	Conformity	
6	Behaviour during Perforation (Static Puncture Test)	N	3520	2500 Min	Yes	IS:16078
7	Height of fall without perforation a) Falling Height : 1100mm b) Steel Cylinder mass: 500gm c) Ball Diameter : 12.7mm	mm	No Perforation Observed at 1100 mm height	1100 Min.	Yes	IS:15909
8	Cold Crack Resistance at Low temperature (At -35°C for 60 minute)	-	No Crack observed	Shall not break/Crack	Yes	
9	Dimensional Stability (At 80°C for 6 hour)	%	0.92	3.0 Max.	Yes	
10	Change in dimension (At 70°C for 2 hour)	-	Stable	Stable	Yes	
11	Strength of welded seam shear resistance	N/50mm	1516 (sample broken from parant material)	1050 Min.	Yes	IS:15909
12	Flammability (i) Horizontal burning rate a) Flame Height: 38mm b) Applyed Flame: 15 sec.	mm/min.	5.2	100 Max.	Yes	
13	Flammability (i) Vertical burning rate a) Flame Height: 40mm b) Applyed Flame: 15 sec.	mm/min.	11.7	100 Max.	Yes	
14	Unit Weight	gm/m²	2786	-	-	
15	Signal layer Thickness (White colour layer) (optical measuring)	mm	0.2	0.20 ± 0.02 mm (As Per Clause No. 3.2)	Yes	

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Table 3. Third party Test Reports of Geo Textile-1

S. No.	Name of Test	Unit	Result	Requirement (As per customer)	Conformity	Test Method
1.	Tensile Strength			1000 Min.		DIN EN: 29073(Pt3)
	(a) One Direction	N/50mm	1458		Yes	
	(b) Other Direction	N/50mm	1152		Yes	
2.	Extension at break			70 Min.		DIN EN: 29073(Pt3)
	(a) One Direction	%	77		Yes	
	(b) Other Direction	%	80		Yes	
3.	Extension (At 30% tensile strength)	%	39	20 Min.	Yes	DIN EN: 29073(Pt3)
4.	Resistance to Puncture	N	3820	2000 Min.	Yes	DIN EN ISO:12236

Table 4. Third party Test Reports of Geo Textile-2.

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S. No.	Name of Test	Unit	Result	Requirement (As per customer)	Conformity	Test Method
1.	Unit weight	gm/m²	563	500 Min.	Yes	EN: 29073-1
2.	Thickness	mm			Yes	ISO: 1765
	(a) At 0.02 bar	mm	4.16	3.9 Min.	Yes	
	(b) At 2.0 bar	mm	2.26	1.9 Min.	Yes	
3.	Permeability in Plain	cm/Second			Yes	Guideline of ASTM D4491
	(a) At 0.02 bar	cm/Second	5.3×10^{-1}	5×10^{-1} Min.	Yes	
	(b) At 2.0 bar	cm/Second	28.7×10^{-2}	5×10^{-2} Min.	Yes	
4.	Resistance to Acid &	%				ISO: 12960 & DIN EN: 29073(Pt3)
	Alkali (At 60°C for 72 hour) (i) Loss of Tensile Strength					
	(a) An Inorganic base Ca(OH)2 (PH-12.1)	%	Pass	10 Max.		
	(b) An Inorganic acid H2SO4 with ferric sulphate and ferrous sulphate (PH. 2.1)	%	Pass	10 Max.		

GEO TEXTILE TESTING AS PER EN-29073


Fig.1 Sample cutting under progress at lab


Fig.3 Tensile Strength & Extension at break- N/50mm


Fig.2 Sample identification marking


Fig.4 Resistance to Puncture-(N)

VI. METHODOLOGY

MB LIFE WP 760

High performance Crystalline Waterproofing and Durability Enhancing admixture for concrete & mortars.

•Powder waterproofing admixture for cement- based grout
•Reduces capillary absorption and enhances workability.
•Ideal for pressure grouting and contact sealing.
•Dosage: 0.5% / 0.8 %/ 1% of cement.

Material description

MB LIFE WP 760 is a hydrophilic crystalline powder admixture for concrete to achieve high resistance to water ingress. It is based on a blend of Portland cement, processed silica sand and special catalytic agents which converts hydration by-products to solid crystalline formation in the water transporting capillary tracts and hydration pores, thus rendering the concrete relatively impermeable and increasing durability.

METHODOLOGY

1) Sample preparation with varying admixture dosages

2) Marsh cone test for workability / Viscosity, (30 to 40 second)

3) Permeability test (By Permeability Test Apparatus)

4) Compressive strength test at 7 and 28 days

Table 5. Sample Grout Mix Proportion

Mix ID	Cement (kg)	Water (kg)	Admixture Type	Dosage (%)	Dosage Details (kg)	Remarks
M1	1	0.5	None	0%	0.00	Control Mix
M2	1	0.5	Superplasticizer (PCE)	0.5%	0.005	Improve workability
M3	1	0.5	Superplasticizer (PCE)	1.0%	0.010	Higher dosage
M4	0.9	0.5	Silica Fume	10%	0.10	10% cement replaced
M5	0.85	0.5	Silica Fume	15%	0.15	15% cement replaced
M6	0.8	0.5	Fly Ash	20%	0.20	20% cement replaced
M7	0.7	0.5	Fly Ash	30%	0.30	30% cement replaced
M8	0.8	0.5	Fly Ash + PRA	20% + 1.0%	0.20 FA + 0.010 PRA	Synergistic effect
M9	0.9	0.5	SF + SP + PRA	10% + 0.5% + 1%	0.10 SF + 0.005 SP + 0.010 PRA	Triple blend mix
M10	1	0.45	Waterproofing Agent(MB Life WP760)+1% SP	0.5%	0.005	Reduced permeability
M11	1	0.45		0.8%	0.008	
M12	1	0.45		1%	0.010	

VII. TEST RESULT AND ANALYSIS

TEST RESULT

Table 6. Comparison

TRIAL NO.	CONTROL	MB LIFE WP760 (0.8%)
W/C RATIO	0.45	0.45
Viscosity, s	38	37
Density, g/cc	1.97	1.99
Initial Setting Time.min	133	130
Final Setting Time.min	215	210
Bleeding at 2hrs, %	1.5	1.5

The table presents a comparison between control concrete and concrete containing MB LIFE WP760 at a dosage of 0.8%, both prepared with the same water–cement ratio of 0.45. The viscosity of the MB LIFE WP760 mix is slightly lower (37 seconds) than the control (38 seconds), indicating that the admixture maintains workability without making the mix thicker. The density of the treated concrete is marginally higher at 1.99 g/cc compared to 1.97 g/cc, suggesting slightly denser and more compact concrete. The initial and final setting times for the MB LIFE WP760 mix are slightly reduced—130 minutes initial and 210 minutes final—showing that the admixture does not delay setting and allows normal to slightly faster hydration. Bleeding at 2 hours remains the same for both mixes at 1.5%, confirming that the waterproofing admixture does not increase surface water accumulation. Overall, the results indicate that MB LIFE WP760 maintains workable, stable, and consistent fresh concrete properties while improving density and showing no adverse effects on setting or bleeding.

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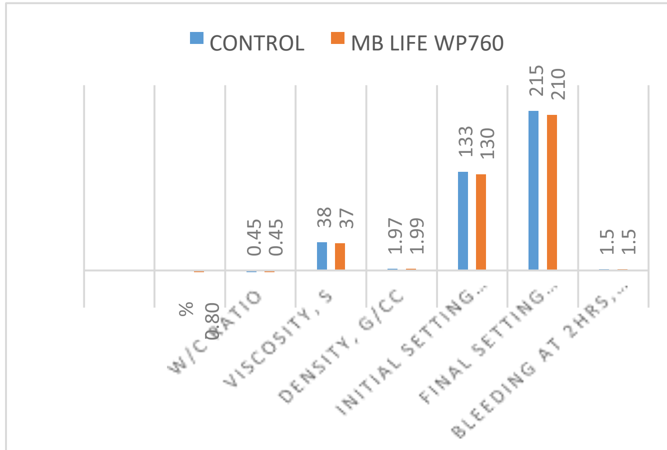

Fig.5. Comparison test Result.

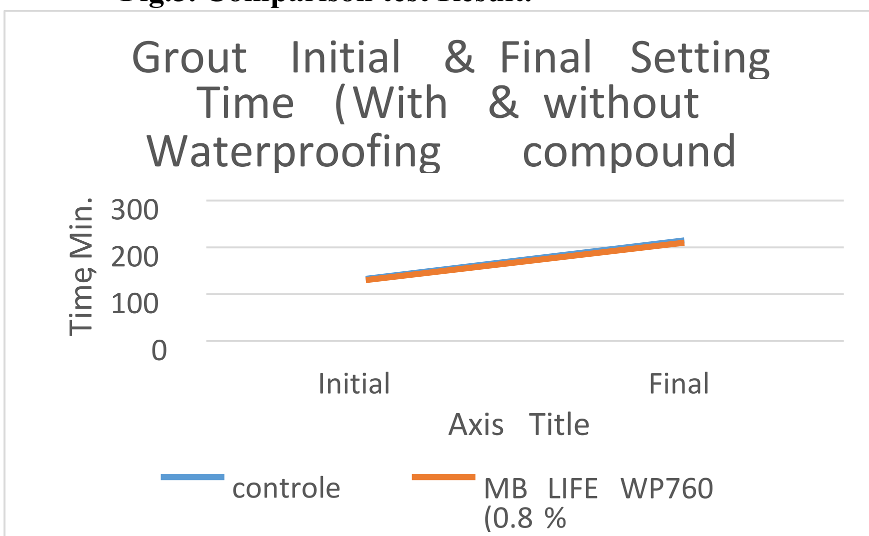

Fig.6 Grout Initial & Final Setting Time (With & without Waterproofing compound.

Table 7. Comparison on Compressive Strength, MPa

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TRIAL NO.	CONTROL	MB LIFE WP760 -0.80%
3 days Compressive Strength, MPa	**16.5**	**17.5**
7 days Compressive Strength, MPa	24	22.5
28 days Compressive Strength, MPa	33.2	33.9
Water penetration, mm	15.2	6.5

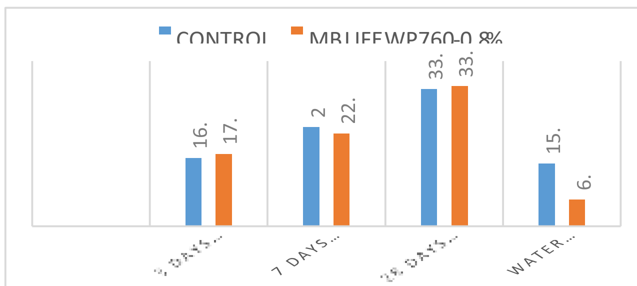

Fig.7 Comparison on Compressive Strength, MPa

The table compares the performance of normal control concrete (1% Mudrock chemiflow 100) with concrete containing the MB LIFE WP760 waterproofing admixture (1% mudrock Chemi flow100) . At days, the compressive strength of MB LIFE WP760 concrete is slightly higher than the control, showing faster early strength development. At 7 days, the strength is marginally lower compared to the control, which is a common effect of waterproofing admixtures due to modifications in hydration. However, at 28 days, the MB LIFE WP760 mix again exceeds the control concrete, indicating that the admixture does not negatively impact the final strength and even improves long-term performance slightly. The most significant improvement is seen in the water penetration test, where penetration depth is reduced from 15.2 mm in the control mix to just 6.5 mm with MB LIFE WP760. This demonstrates a major enhancement in waterproofing efficiency, reduced permeability, and increased concrete durability. Overall, the admixture helps produce denser, stronger, and more water-resistant concrete.

(a)

(b)

(c)

Fig.8 (a)-(c) Test Preparation

VIII. CONCLUSION AND FUTURE SCOPE

CONCLUSION

Based on the comparative evaluation of control concrete and concrete modified with 1% admixture
Chemi Flow 100 for workability & MB LIFE WP760 at a dosage of 0.8%,&, the results clearly demonstrate that the waterproofing admixture enhances overall performance without negatively affecting fresh or hardened properties. The fresh concrete parameters—such as viscosity, density, setting time, and bleeding—remain stable, indicating that MB LIFE WP760 does not compromise workability or cause undesirable changes in mix behaviour. A slight increase in density suggests improved particle packing and reduced voids, which supports better long-term durability. The setting times for the treated mix are marginally shorter, showing that the admixture allows the cement hydration process to proceed normally while maintaining practical workability on-site.

In terms of hardened properties, MB LIFE WP760 shows positive effects on compressive strength. At 3 days, the treated mix exhibits higher early strength (17.5 MPa compared to 16.5 MPa), indicating improved early hydration. Although the 7-day strength shows a slight reduction, the 28-day strength surpasses the control concrete (33.9 MPa vs. 33.2 MPa), confirming that long-term strength development is either maintained or slightly enhanced. The most significant improvement is observed in water penetration results: the treated concrete shows a substantial reduction from 15.2 mm to 6.5 mm, highlighting the superior waterproofing and densification effect of MB LIFE WP760.

FUTURE SCOPE

The present study demonstrates the effectiveness of MB LIFE WP760 in improving permeability control, strength development, and durability performance of concrete for contact grouting applications. However, there remains significant scope for further exploration to enhance the understanding and real- world applicability of crystalline waterproofing admixtures in tunneling and underground construction. Future studies may focus on long-term durability assessments such as freeze–thaw resistance, sulphate attack, carbonation depth, and chloride ion penetration to evaluate the material's behaviour under aggressive underground conditions. Additionally, large-scale field trials in actual tunnel grouting operations can help validate laboratory findings and establish practical guidelines for dosage, mix optimization, and pumping characteristics.

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