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

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Abstract

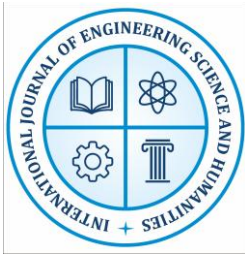
Contact grouting is an important technique in tunneling applications for filling voids between the tunnel lining and surrounding ground and reducing water ingress. However, conventional cement-based grout may exhibit relatively high permeability due to capillary pores and microcracks. This study experimentally investigates the effectiveness of crystalline admixture in controlling the permeability of contact grout. Grout specimens with different dosages of crystalline admixture are prepared and evaluated through permeability, water penetration, and strength tests. The experimental results are used to determine the influence of crystalline admixture on pore sealing, water resistance, and overall grout performance. The study aims to identify an optimum admixture dosage that can improve the water-tightness and durability of contact grouting, thereby enhancing its suitability for tunneling applications.

Keywords: Contact Grouting; Crystalline Admixture; Permeability Control; Tunnel Grouting; Water Tightness

I. INTRODUCTION

Tunnel construction has become an important part of modern infrastructure development because of the increasing demand for underground transportation, water conveyance, hydropower, railway, and urban utility systems. The safety and durability of a tunnel depend not only on the structural performance of its lining but also on the quality of the contact between the lining and the surrounding soil or rock mass. During excavation and lining construction, irregularities, overbreaks, settlement, and construction tolerances can create voids between the tunnel lining and the surrounding ground. If these voids are not properly filled, they can reduce effective ground–lining interaction and create preferential pathways for groundwater movement [1].

Contact grouting is widely used to fill these voids and improve the contact between the tunnel lining and surrounding ground. Cement-based grout is commonly selected because of its availability, economical nature, ease of preparation, and compatibility with concrete and rock [2]. The grout is injected under controlled pressure into the spaces behind the lining, where it fills cavities and hardens to form a relatively continuous cementitious zone. In addition to



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improving contact and load transfer, an effective grout system can help reduce groundwater seepage and improve the overall durability of the tunnel structure.

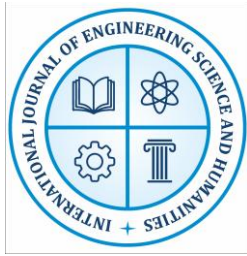
One of the major challenges associated with conventional cementitious grout is its permeability. Hardened grout contains capillary pores, interconnected voids, and microcracks that may provide pathways for water penetration. The permeability of grout is influenced by several factors, including water-to-cement ratio, cement type, curing conditions, degree of hydration, pore structure, and the presence of chemical or mineral admixtures. High permeability can allow groundwater to migrate through the grouted zone, potentially causing seepage, dampness, deterioration of cementitious materials, and long-term durability problems in underground structures [3].

Permeability control is therefore a key requirement for contact grouting in tunnels, particularly in areas subjected to high groundwater pressure. A low-permeability grout should possess sufficient flowability to penetrate narrow gaps and cavities while developing adequate strength and water resistance after hardening. However, reducing permeability only by decreasing the water-to-cement ratio may adversely affect grout workability and injectability. This creates a need for suitable admixture technologies that can improve water resistance without significantly compromising the fresh and hardened properties required for practical grouting operations [4].

Crystalline admixtures are promising materials for improving the water-tightness of cement-based systems [5]. These admixtures contain reactive components that interact with cement hydration products in the presence of moisture. The reactions can promote the formation of insoluble crystalline products within capillary pores and microcracks. These products can partially block or reduce the continuity of water-flow pathways, thereby decreasing water penetration and improving the impermeability of the cementitious matrix. The self-sealing characteristics associated with crystalline technology make it particularly attractive for underground structures that remain exposed to moisture or groundwater.

The effectiveness of crystalline admixture depends strongly on its dosage and interaction with the cementitious matrix. An insufficient dosage may provide limited pore-blocking action, whereas an excessive dosage may influence grout flowability, setting behavior, strength development, or other engineering properties [6]. Therefore, experimental evaluation is necessary to understand the relationship between crystalline admixture content and permeability performance. Determining an optimum dosage is particularly important for contact grouting, where the material must satisfy both injectability in the fresh state and water-tightness and mechanical stability in the hardened state.

The present study experimentally investigates the permeability control in contact grouting using crystalline admixture for tunneling applications. Cement-based grout mixes incorporating



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different dosages of crystalline admixture are prepared and experimentally evaluated. The investigation focuses primarily on permeability and water penetration characteristics, while associated strength and workability properties are also considered to assess the overall suitability of the modified grout [7]. The experimental results are used to identify the influence of crystalline admixture on the performance of contact grout and to determine an appropriate dosage for improving water resistance.

The study is expected to provide useful information for the development of more durable and water-resistant grout materials for tunnel construction. Effective permeability control can reduce groundwater ingress, improve the durability of tunnel lining systems, minimize maintenance requirements, and enhance the long-term performance of underground infrastructure. The findings may therefore contribute to the practical application of crystalline-admixture-modified grout in contact grouting and other water-resistant tunneling applications [8].

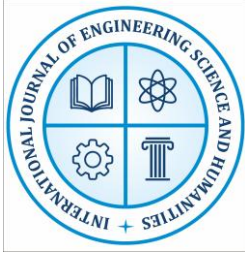
II. CRYSTALLINE ADMIXTURE FOR TUNNELING APPLICATIONS

Crystalline admixtures are specialized cementitious additives used to improve the water-tightness and permeability resistance of concrete and grout systems. They are particularly useful in tunneling applications where structures are continuously exposed to groundwater, seepage pressure, and moisture. When incorporated into cement-based grout, the reactive chemicals present in the crystalline admixture interact with cement hydration products in the presence of water and form insoluble crystalline compounds. These compounds develop within capillary pores and microcracks, reducing the continuity of pathways through which water can penetrate [9].

In contact grouting, crystalline admixtures can improve the performance of grout injected into the gap between the tunnel lining and surrounding soil or rock. The modified grout can provide improved resistance to groundwater penetration while maintaining the required filling and bonding characteristics. This is important because water infiltration behind the lining may lead to leakage, deterioration of the grout, corrosion of reinforcement or embedded components, and reduction in the long-term durability of the tunnel system [1, 10].

The effectiveness of crystalline admixture depends on several factors, including admixture dosage, water-to-cement ratio, cement type, curing conditions, grout composition, and exposure conditions. An optimum dosage is required because a very low concentration may not provide sufficient pore-sealing action, while excessive dosage may adversely affect workability, setting behavior, or strength. Therefore, experimental investigation is necessary to determine the dosage that provides the best balance between permeability reduction and mechanical performance.

For tunneling applications, crystalline-admixture-modified grout offers several potential advantages:



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- Reduction in water permeability through pore and microcrack blocking.
- Improved water-tightness of the grouted zone behind the tunnel lining.
- Reduced groundwater seepage through voids and discontinuities.
- Improved durability under continuously wet underground conditions.
- Potential self-sealing action when moisture is available.
- Better protection of the tunnel lining system against water-related deterioration.
- Improved long-term service performance of contact grouting systems.

Thus, the incorporation of crystalline admixture into contact grout can be considered a promising approach for controlling permeability in tunnel construction. In the present research, different crystalline admixture dosages can be investigated experimentally to evaluate their effects on permeability, water penetration, compressive strength, and grout performance, with the objective of identifying an optimum dosage suitable for tunneling applications [8].

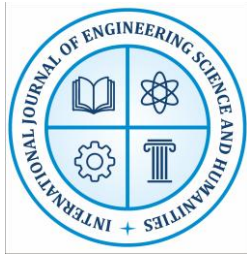
III. RESEARCH GAP

Although contact grouting is widely used in tunneling to fill voids between the tunnel lining and surrounding ground, conventional cement-based grout can still exhibit permeability due to capillary pores, interconnected voids, and microcracks. Previous studies have investigated various methods for reducing grout permeability, including modifications in water-to-cement ratio, supplementary cementitious materials, and different chemical admixtures [4, 5]. However, comparatively limited experimental research has specifically focused on the use of crystalline admixtures in cement-based contact grouting for tunneling applications.

A major research gap exists in establishing a clear relationship between crystalline admixture dosage and the permeability characteristics of contact grout. Although crystalline materials are known for their pore-blocking and water-resistant behavior, their optimum dosage for tunnel contact grouting is not sufficiently established under different grout conditions. Excessive admixture content may also influence flowability, setting characteristics, strength, and injectability, which are critical requirements for practical tunnel grouting [10].

Furthermore, many existing investigations primarily focus on crystalline admixtures in conventional concrete or waterproofing applications rather than specifically evaluating their performance in contact grout placed behind tunnel linings. The interaction between crystalline admixture, grout pore structure, water penetration, and mechanical performance requires further systematic investigation. There is also a need to evaluate permeability reduction together with strength and workability rather than considering water resistance as an isolated property.

Another important gap is the limited availability of experimental data for identifying an optimum crystalline admixture dosage that provides adequate permeability control without negatively affecting the fresh and hardened properties of grout [7]. The influence of curing and moisture



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conditions on the development of crystalline products and subsequent permeability reduction also requires further investigation.

Therefore, the present study addresses these gaps by experimentally investigating cement-based contact grout containing different proportions of crystalline admixture. The study evaluates the effect of admixture dosage on permeability, water penetration, strength, and related grout properties. The results are intended to identify an optimum dosage and establish the potential of crystalline-admixture-modified grout as a durable and water-resistant material for tunneling applications [9].

IV. 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: 200–500 ml per 50 kg 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.

Areas of application

MB LIFE WP 760 should be used in all structural concrete that is constantly or intermittently in contact with water or other aggressive environments such as sea walls, tunnels, basements, structural and pre-cast concrete. MB LIFE WP 760 can also be used as crystalline waterproofing admixture for cement mortars and plasters.

To waterproof structures such as:

- Water tanks, Reservoirs
- Building Basements & foundations

Features and benefits

- Provides resistance to water penetration either under hydrostatic pressure or capillary absorption. Imparts integral water tightness to structures by reducing concrete permeability
- Protects from waterborne corrosive agents. Permanently active crystalline action is reactivated by contact with water.
- Equally effective against both positive and negative water pressure or osmotic pressure.



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- Reduced sulphate attack & efflorescence.
- Zero VOC (Volatile Organic Content)
- Seals hair line cracks.
- Allow concrete to breath.
- Non-toxic Safe with potable water applications.
- Do not reduce compressive strengths Powder-easy to use in pre-batched renders in other range of MBT admixtures is advised to achieve
- Cold application method prevents smoke, odors and noise. Permeability reducing admixture as per ACI 212. 3R-2010

Product Information

Table 1. Product Information

Aspect	Free-flowing grey powder
Bulk Density	1.350 ± 0.02 g/cm ³
Chloride Ion Content	< 0.1% by mass
Alkali Content	< 5% by mass
Compressive Strength	90% of control concrete
Air Content in Fresh Concrete	≤ 1.5% by volume
Dry Material Content	> 99.5%

Test Certification / Approvals

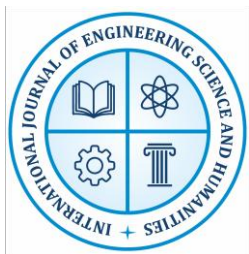
- IS:2645-2003
- Meets ASTM C 494/C 494 M requirements for Type S (Specific Performance Admixture)
- Tested as per DIN 1049 Pt V, IS 3085-1965 (Reaffirmed 2021)

Dosage

As a guide a dosage of 0.8% - 2% by weight of cementitious binder is recommended. The optimum dosage of crystalline to meet specific requirements should always be determined by conducting laboratory and batch trials. For additional information on MB LIFE WP 760 or on its use in developing concrete mixes with special performance characteristics, contact your local MBT representative. Points to remember when producing waterproof and durable concrete:

- Ensure water/cement ratio is less than 0.5.
- Addition of good plasticizer from the minimum water/cement ratio.
- Place concrete quickly and compact it well.
- Ensure complete curing with a recommended curing compound.
- Low dosage, economical.

Application



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MB LIFE WP 760 is a ready-to-use powder which is dispensed into the concrete together with cement. Following sequence of mixing shall enable best performing waterproofing mix:

- Batch coarse aggregates
- Batch fine aggregates
- Batch cement & mineral admixtures
- Sprinkle MB LIFE WP 760

Suggested Specification

The crystalline powder water proofer and durability enhancer shall be MB LIFE WP 760, active catalytic agents based. The product shall comply with IS: 2645- 2003 when tested at a dosage of 0.8% - 2% by weight of cementitious binder. The product must be free of chlorides.

Compatibility

MB LIFE WP 760 is compatible with most of the products under the MB GLEN, MB POLY, MB DEL & MB POZZ series. Use MBT VMA as viscosity modifying agent in self- compacting concrete. MB LIFE WP 760 is also compatible with slag and pozzolans such as fly ash and silica fume.

Corrosivity - non-chloride, non- corrosive

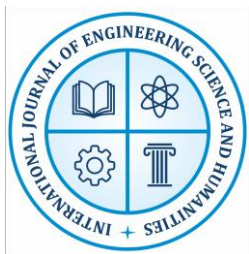
MB LIFE WP 760 admixture will neither initiate nor promote corrosion of reinforcing steel embedded in concrete, prestressed concrete or concrete placed on galvanized steel floor and roof systems. Neither calcium chloride nor any calcium chloride-based ingredients are used in the manufacture of MB LIFE WP 760 admixture. In all concrete application, MB LIFE WP 760 admixture will conform to the most stringent or minimum chloride ion limits currently suggested by construction industry standards and practices.

Workability

MB LIFE WP 760 has little or no effect on workability of concrete. Prior site trials are advised to assess the effect, and any increase or decrease in the workability can be adjusted by adjusting the admixture dosage or amount of water in use. It is strongly recommended that concrete should be properly cured particularly in hot, windy and dry climates. To achieve longer workability period please use MB POZZ RSS.

V. 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



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VI. TEST RESULT

Table 2. 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

Interpretation of Fresh Concrete Properties

The fresh concrete test results for the control mix and the mix containing MB LIFE WP760 at 0.8% dosage indicate that the waterproofing admixture has only a minor influence on the fresh properties of the concrete. Both mixes were prepared at the same water-to-cement (W/C) ratio of 0.45, allowing a direct comparison of the effect of the admixture.

The **viscosity** decreased slightly from 38 s for the control mix to 37 s with MB LIFE WP760. This small reduction indicates a marginal improvement in flowability without causing any significant change in the consistency of the mix. The density increased from 1.97 g/cc to 1.99 g/cc, suggesting a slightly denser and more compact fresh mix, which may contribute to reduced internal voids after hardening.

The initial setting time decreased from 133 minutes to 130 minutes, while the final setting time decreased from 215 minutes to 210 minutes after incorporating MB LIFE WP760. These changes are relatively small and indicate that the admixture does not significantly disturb the setting characteristics of the cementitious system. The concrete therefore retains adequate time for handling, placement, and finishing.

The bleeding at 2 hours remained unchanged at 1.5% for both the control and modified mixes. This indicates that MB LIFE WP760 does not increase the tendency of water to separate from the fresh concrete. Maintaining the same bleeding value is beneficial because excessive bleeding can increase capillary channels and adversely affect the permeability and durability of hardened concrete.



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Overall, the results demonstrate that MB LIFE WP760 at 0.8% dosage maintains the fresh concrete properties with only minor variations in viscosity, density, and setting time, while bleeding remains unchanged. This indicates good compatibility of the admixture with the concrete mixture and suggests that its use for improving waterproofing performance does not cause significant adverse effects on fresh-state behavior.

Table 3. Comparison on Compressive Strength, MPa

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

At 3 days, the compressive strength increased from 16.5 MPa for the control mix to 17.5 MPa for the MB LIFE WP760 mix, representing an increase of approximately 6.1%. This indicates slightly improved early-age strength development.

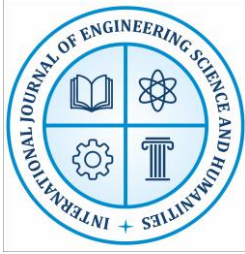
At 7 days, the modified concrete recorded 22.5 MPa, compared with 24.0 MPa for the control concrete. This represents a reduction of approximately 6.25%. However, this decrease at 7 days does not indicate a significant deterioration in overall performance because the modified concrete subsequently achieved a higher 28-day strength.

At 28 days, the compressive strength increased from 33.2 MPa to 33.9 MPa, corresponding to an improvement of approximately 2.1%. This indicates that the incorporation of MB LIFE WP760 does not adversely affect long-term compressive strength and may provide a slight improvement.

Water Penetration

The most significant improvement is observed in water penetration. The control concrete exhibited a penetration depth of 15.2 mm, whereas the concrete containing MB LIFE WP760 showed only 6.5 mm.

This corresponds to a reduction of approximately **57.2% in water penetration**. Such a substantial reduction indicates a considerable improvement in the water-tightness and



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impermeability of the modified concrete. The result suggests that MB LIFE WP760 effectively reduces the movement of water through capillary pores and interconnected pathways within the concrete matrix.

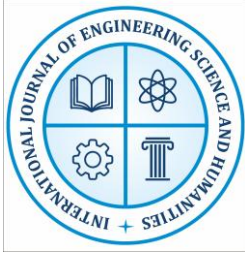
Overall, the experimental results demonstrate that 0.8% MB LIFE WP760 provides significant waterproofing benefits while maintaining comparable compressive strength. The particularly large reduction in water penetration highlights its potential for applications requiring enhanced resistance to water ingress, such as tunnels, underground structures, basements, water-retaining structures, and contact grouting systems.



Fig.1. Monitoring.



Fig.2. Inspection.



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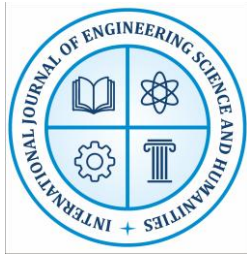
Fig.3. Tunnel Excavation and Lining Works During Construction.

VII. CONCLUSION

Based on the comparative assessment of control concrete and concrete incorporating MB LIFE WP760 at a dosage of 0.8%, it can be concluded that the waterproofing admixture improves the overall performance of concrete without causing any significant adverse effects on its fresh or hardened properties. The fresh concrete characteristics, including viscosity, density, setting time, and bleeding, remain within acceptable ranges, indicating that the incorporation of MB LIFE WP760 does not adversely affect the workability or handling characteristics of the concrete. The slight increase in density may indicate improved compactness and reduced internal voids, which can contribute to enhanced durability and resistance to water penetration. The marginal variation in setting time further suggests that the admixture is compatible with the cement hydration process and does not cause significant disruption during concrete placement.

The hardened concrete results also demonstrate the beneficial influence of MB LIFE WP760. The compressive strength at 3 days increased from 16.5 MPa for the control mix to 17.5 MPa for the modified mix, indicating improved early-age strength development. Although a minor reduction was observed at 7 days, the 28-day compressive strength increased from 33.2 MPa to 33.9 MPa, demonstrating that the long-term strength of the concrete was maintained and slightly improved with the incorporation of the admixture.

The most notable improvement was observed in the water penetration resistance of the concrete. The penetration depth decreased significantly from 15.2 mm in the control concrete to 6.5 mm in



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the MB LIFE WP760-modified concrete. This substantial reduction indicates improved impermeability and suggests that the admixture effectively reduces the movement of water through the concrete matrix. The improved water resistance may be attributed to the densification of the cementitious matrix and reduction in interconnected pores and capillary pathways.

Overall, the experimental findings indicate that MB LIFE WP760 at 0.8% dosage is effective in improving the water-tightness of concrete while maintaining its fresh properties and compressive strength. The significant reduction in water penetration demonstrates its potential for applications where resistance to moisture ingress is a critical requirement. Therefore, MB LIFE WP760 can be considered a suitable waterproofing admixture for producing more durable and water-resistant concrete structures.

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