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

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Abstract
The control of permeability in contact grouting plays a crucial role in ensuring the long-term stability and durability of underground structures, particularly in tunneling applications. This review focuses on the experimental investigations conducted on the use of crystalline admixtures (CA) in cementitious grouts to enhance impermeability and self-sealing capacity. Crystalline admixtures chemically react with moisture and unhydrated cement particles to form insoluble needle-like crystals within the pore structure, thereby blocking capillary pathways and reducing water permeability. The study evaluates various parameters influencing the grout performance, such as water–cement ratio, dosage of crystalline admixture, curing conditions, and pressure grouting techniques. Laboratory-based permeability tests, scanning electron microscopy (SEM), and microstructural analyses are reviewed to understand the mechanisms of crystal formation and pore filling. The results from different investigations indicate that the inclusion of crystalline admixtures significantly decreases permeability, improves durability, and enhances the self-healing capacity of the grout matrix. This review concludes that crystalline admixture–modified contact grouting is a promising approach for tunnel waterproofing and ground stabilization, offering sustainable and cost-effective solutions for modern tunneling projects.
Keywords: Crystalline admixture (CA), contact grouting, permeability control, tunnel waterproofing, self-healing concrete.

I. INTRODUCTION

Concrete is one of the most widely used construction materials due to its versatility, durability, and cost-effectiveness [1,2,3,4]. 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 [5,6,7]. 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 [8,9,10,11]. Applied during mixing, these admixtures react with cement hydration byproducts to form insoluble crystalline structures within the concrete matrix [11,12,13,14], effectively filling pores and reducing permeability [15]. Furthermore, crystalline admixtures have shown to enhance compressive strength across various applications [9,6,7]. The development and application of crystalline admixture technologies have significantly advanced over time [8,9]. Initially, the primary concern in concrete construction was addressing water ingress, 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. In the early stages, researchers and engineers focused on identifying 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. 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 sophisticated 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.

II. 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.

III. PERMEABILITY CONTROL IN CONTACT GROUTING

Permeability control in contact grouting is a critical factor in ensuring the stability, durability, and waterproofing efficiency of underground structures such as tunnels and shafts. Contact grouting involves injecting cementitious or chemical grout materials into the annular gap between the tunnel lining and the surrounding ground to eliminate voids and prevent water ingress. Effective control of permeability is achieved by optimizing the grout mix design, water–cement ratio, and use of special additives such as crystalline admixtures or silica fume. These materials react chemically with moisture and unhydrated cement particles to form insoluble crystalline structures that fill pores and microcracks within the grout matrix. As a result, the permeability of the hardened grout is significantly reduced, providing a long-lasting seal against groundwater seepage. Proper permeability control not only enhances the waterproofing capability of the tunnel system but also improves the overall structural integrity and extends the service life of the underground construction.

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IV. 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. 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.

V. IMPACT OF PERMEABILITY CONTROL IN TUNNELING APPLICATION

Permeability control has a significant impact on the safety, performance, and longevity of tunneling projects. In underground environments, excessive water ingress can lead to structural weakening, increased maintenance costs, and operational hazards. By effectively controlling permeability through optimized grouting and material selection, such as the incorporation of crystalline admixtures, tunnels achieve enhanced waterproofing and stability. Reduced permeability minimizes the risk of groundwater leakage, corrosion of reinforcement, and deterioration of concrete linings. It also prevents the migration of fine soil particles, which can cause ground settlement and void formation around the tunnel structure. Furthermore, improved impermeability ensures that pressure balance is maintained during construction, reducing the likelihood of water inflow incidents. Overall, permeability control contributes to increased structural integrity, reduced lifecycle costs, and improved durability, making it a crucial parameter in modern tunneling design and construction practices.

VI. LITERATURE REVIEW

Marah Ali Ammar et al.[1] The durability and strength of concrete in construction can be significantly compromised by permeability issues, which pose considerable challenges to its long-term effectiveness and reliability. By analyzing six selected articles from the Scopus database, this study meticulously synthesizes findings on the effectiveness of CAs in improving these essential properties of concrete. The research meticulously documents and analyzes key variables such as the CA dosage, water–cement ratio, evaluation duration, and treatment conditions, providing a thorough understanding of the factors that influence the performance of CAs in concrete. The results robustly indicate that CAs significantly reduce concrete permeability, thereby enhancing its resistance to water and other detrimental substances, and simultaneously boosts the compressive strength, leading to stronger and more durable concrete structures. However, the study also reveals that the impact of CAs can vary considerably depending on the specific conditions and methodologies employed in the individual studies. This underscores the importance of standardized testing procedures to ensure consistent and comparable results across different studies. This research provides valuable insights for optimizing the use of CAs in concrete formulations, ultimately aiming to improve the durability, performance, and sustainability of concrete in construction applications.

Mengjie Wang et al.[2] Cement grout is traditionally used for treating water leakage distress in tunnels. However, traditional cement grout has the disadvantages of a poor anti-seepage performance, long setting time, and slow strength gain. To this end, a high-performance cement-based capillary crystalline waterproofing (CCCW) grouting material was synthesized using cement, capillary crystalline material, and several admixtures. The influences of the material proportions on the viscosity, bleeding rate, and setting time of the fresh grout, as well as the permeability coefficient of the grouted aggregate and the unconfined compression strength of the hardened grout material, were systematically studied. The mineralogy and microstructure of the CCCW grouting material were examined using X-ray diffraction, industrial computed tomography, and scanning electron microscopy. The results indicated that the capillary crystalline material PNC803 was not suitable for mixing with bentonite, sodium chloride, and triethanolamine in cementitious slurries, but it can produce excellent synergistic effects with sulfate, calcium chloride, and triisopropanolamine. An analysis of the microstructure of the CCCW grouting material showed that the PNC803 and additives can promote the hydration of cement, which yields more hydration products, sealing water passage and filling micro voids and therefore leading to enhanced waterproofing and strengthening effects. These research results could improve the applicability of CCCW material in tunnel engineering.

Sihui Dong, Xinyu Zhang et al.[3] The surrounding rock of tunnels in cold regions are susceptible to the freeze–thaw cycle resulting from the combination of low temperatures and moisture during tunnel service. The phenomenon will not only lead to the expansion of pores and fissures in the surrounding rock of the initial tunnel, but also destroy the integrity of the rock. This destruction will have a serious impact on tunnel structure and rail transit operation safety. At present, the commonly used thermal insulation measures have some problems such as maintenance difficulties, low economic efficiency, and safety hazards. Therefore, it is urgent to develop a kind of tunnel maintenance grouting material with insulation and anti-permeability, which has the characteristics of simple operation, easy preparation and application. We independently developed a composite grouting material composed of polyurethane (PU), epoxy resin (E-51) and acrylic powder (PMMA). Through the material combustion test, magnesium hydroxide was selected as the flame retardant additive. Moreover, we measured the thermal conductivity, water absorption, apparent density, porosity and strength characteristic parameters. The thermal insulation and anti-permeability characteristics of the composites were also analyzed. The results indicated that the thermal conductivity of the new composite grouting material is 6.3% lower than the PU before adding flame retardant. Compared with the PU with flame retardant, the water absorption decreased by 74.4% and the ultimate strength increased by 33.3%. For the area with an average temperature lower than − 10 °C, we recommend the ratio scheme of E-51: 3%; PMMA: 15%. For the area with high water content in the surrounding rock of the tunnel, we recommend the ratio scheme of E-51: 15%; PMMA: 3%. This study provides new ideas for material preparation and tunnel insulation methods for anti-freezing measures in tunnels during their operational period in cold regions.

Xiaohua Yang, Kunlong Zheng et al.[4] The study investigates a new chemical grout by mixing the main agent, auxiliary agent, catalyst, foam stabilizer, solvent, and water, to treat the distress of railway tunnel. The orthogonal design was used to obtain 16 groups of grout proportion schemes, and reasonable proportion parameters were screened using laboratory and field tests. Additionally, this study included detailed research on the grout performance. The test results showed that the proportion schemes of groups 3, 4, and 15 grout were the most reasonable. In particular, for group 3, the viscosity is 663 MPa·s, the curing time is 119 s, the foaming capacity is 1589%, and the compressive strength is 20.16 MPa. For group 4, the viscosity is 663 MPa·s, the curing time is 137 s, the foaming capacity is 1809%, and the compressive strength is 17.76 MPa. For group 15, the viscosity is 281 MPa·s, the curing time is 98 s, the foaming capacity is 1173%, and the compressive strength is 26.79 MPa. Groups 4 and 15 grouts were used to treat the frost boiling and track bed subsidence in existed railway tunnels. Based on this, field monitoring showed that muddy water became clear water with an average depth of only 4 mm in the drainage ditch and that the irregular subsidence of the track bed was also solved after treatment. According to the aforementioned experimental research and analysis, it is proven that new grout not only exhibits a reasonable solidification time, high strength, and excellent waterproofing and impermeability with no pollution of the environment but also can be produced by a safe and convenient synthesis method. Group 4 is suitable for treating tunnel seepage, group 15 is suitable for structural reinforcement, and group 3 confers the advantages of seepage prevention, leakage stoppage, and reinforcement.

Kanghao Tan et al.[5] The durability of concrete roads in mountainous regions may be reduced due to underground water infiltration and surface water erosion within highway tunnels. A promising solution is the use of pervious concrete as a drainage subgrade layer to drain away the water, and then to prevent water-induced pavement damage of pavement. For pervious concrete to be an ideal drainage layer for high-traffic loads, it must have compressive strength and permeability coefficient exceeding 25 MPa and 15 mm/s, simultaneously. However, traditional pervious concrete tends to emphasize either in high-strength or high-permeability, depending on its porosity. This study introduces an innovative proportion design method of pervious concrete, which enables higher compressive strength and permeability coefficient by adjusting its skeleton structure, and thus catering to high-traffic load applications. In addition, the workability and setting time of pervious concrete were optimized according to the local environmental conditions, facilitating large-scale and efficient paving of the drainage subgrade. As a result, a drainage subgrade layer with a 28-day compressive strength of 26.43 MPa and permeability coefficient of 18.86 mm/s was successfully applied in a highway tunnel. This study provides a theoretical framework and technical support for widespread application of pervious concrete in drainage subgrade of high-traffic load road.

Shiyang Liu et al.[6] Crystal blockage in highway tunnel drainage systems often leads to a higher groundwater level behind the lining, leading to tunnel lining cracking and leakage. The drainage system mainly consists of circumferential, longitudinal, and transverse drainage pipes, as well as construction joint drainage waterstops. Most studies have carried out macro-experimental analysis on the crystal blockage of drainage systems, but few have been done at the micro-level. In this paper, the micro-laws between typical tunnel drainage materials and $CaCO_3$ crystals at different groundwater temperatures were analyzed by the molecular dynamics analysis software. The results show that (1) CO_3^{2-} and Ca^{2+} have the highest diffusion coefficients when the groundwater temperatures are 338 and 358 K, respectively. Under such conditions, it would be hard for them to form crystals. It is relatively easy for them to crystallize at 288 K. (2) When the groundwater temperature is higher than 318 K, the distance between CO_3^{2-} and Ca^{2+} to crystallize is near 2.34 ± 0.05 Å. When the temperature is higher than 318 K, the distance is around 1.98 ± 0.05 Å. (3) Natural rubber facilitates the adsorption of $CaCO_3$ aqueous solution at temperatures between 298 and 338 K. Polyethylene enhances adsorption at temperatures less than 298 K or higher than 338 K. (4) When the groundwater temperatures are 278 and 348 K, the adsorption occurred more easily at the interface between the $CaCO_3$ aqueous solution and the calcite crystal. After $CaCO_3$ is crystallized, it is more tightly bonded and is less likely to fall off from the polypropylene.

Mostafa Zamanian et al.[7] Collapsible soils, characterized by sudden settlement upon wetting, pose significant geotechnical challenges for infrastructure foundations. While conventional stabilization methods exist, their effectiveness is often limited by non-uniform treatment or environmental concerns. This study systematically evaluates two innovative approaches—permeation grouting and mechanical mixing—using nano-clay (NC) and ordinary Portland cement (OPC) to stabilize such problematic soils. Through comprehensive laboratory experiments, undisturbed soil samples were treated with varying concentrations of NC (0.05–0.25 wt%) and OPC (0.5–2.5 wt%), followed by mechanical testing and microstructural analysis. The mechanical behavior of treated soils was evaluated through direct shear tests on both reconstituted samples and undisturbed samples taken from the centers and sides of grouted specimens at various curing times. Key results show that NC grouting (with the optimal concentration of 0.1 wt%) achieved fairly uniform strength improvement, increasing cohesion from 4 kPa to 35.8 kPa and internal friction angle from 26° to 36.5° after 28 days. In contrast, OPC grouting improved only the central zones (cohesion: 44 kPa at 2.5 wt%), while side specimens showed limited gains (≤14 kPa) due to pore clogging. The mixing method proved ineffective as a soil improvement strategy, particularly for NC-mixed specimens. The study establishes NC permeation grouting as a sustainable and efficient alternative to conventional methods, offering superior spatial consistency with only one-tenth the material requirement of cement-based approaches. It provides both mechanistic insights and practical solutions for collapsible soil stabilization, advancing the field through its novel application of nanomaterial injection technology.

Heng Liu et al.[8] With the rapid acceleration of urbanization in domestic areas, the number of subway and tunnel projects is on the rise. Consequently, there has been a significant increase in the utilization of grouting materials in more complex environments. In response to this trend, engineering practice has raised higher demands for the durability and shear resistance of grouting materials. In particular, there is a growing demand for inert single grout due to its environmentally friendly properties and excellent workability. Previous research has primarily concentrated on optimizing and adjusting the powder mix ratios within the grout to adapt to conditions such as water-rich soft strata. In this study, we focus on a novel type of inert grout, primarily composed of fly ash (FA), lime, bentonite, and fine sand as its main raw materials. By modifying the composition with admixtures such as polycarboxylate ester (PCE) and cellulose ether, the component is optimized to improve the impermeability and shear resistance of the inert grout. The 1H low-field NMR was employed to characterize the transition progress of water in different samples, with the goal of elucidating the various mechanisms through which admixtures affect the grouting materials. The results indicate that both types of admixtures, when used in specific dosages, improve impermeability through distinct mechanisms. Cellulose ether, in particular, exerts a more pronounced influence. The combined use of these admixtures enables targeted adjustments to the grout's shear performance to meet engineering requirements while preserving workability.

Jianshuai Hao et al.[9] Grouting is an effective and practical emergency technique for controlling sudden water ingress in tunnel construction. This study investigated the performance optimization and engineering applicability of a steel slag (SS)-cement-based composite grouting material for water inrush scenarios. The effects of the water-to-cement ratio (W/C), SS content, and water reducer (W*R*) dosage on workability, strength, and microstructure were evaluated. The optimal mix (W/C = 0.5, SS = 8 %, W*R* = 1.5 %) demonstrated high fluidity (25.6 cm), adjustable pumpability (20–50 min), and late-stage compressive strength of 23.43 MPa. Microstructural analysis revealed densification from hydration products, with average pore size reducing from 53 nm to 43 nm. Field application in the Dongdashan Tunnel confirmed excellent water-blocking performance under complex hydrogeological conditions. This work offers a high-performance, sustainable grouting solution that promotes the reuse of industrial by-products.

Huayun Li et al.[10] This research paper systematically investigates the combined influence of fly ash, cementitious capillary crystalline waterproofing (CCCW) materials, and polypropylene fibers on the mechanical properties and impermeability of concrete through comprehensive orthogonal tests. Microscopic morphological changes in the concrete induced by different composite materials are examined via scanning electron microscopy (SEM) and X-ray diffraction (XRD) testing. The objective is to facilitate a beneficial synergetic interaction among these materials to develop highly permeable, crack-resistant concrete. Key findings of this study are: (1) The study unveils the impact of the concentration of three additive materials on the concrete's compressive strength, tensile strength, and penetration height, thereby outlining their significant influence on the mechanical properties and impermeability of the concrete; (2) An integrated scoring method determined the optimal composite dosage of three materials: 15% fly ash, 2% CCCW, and polypropylene fibers at 1.5 kg/m^3. This combination increased the concrete's compressive strength by 12.5%, tensile strength by 48.4%, and decreased the average permeability height by 63.6%; (3) The collective introduction of these three materials notably augments the hydration reaction of the cement, resulting in denser concrete microstructure, enhanced bonding between fibers and matrix, and improved concrete strength and durability.

Jiandong Niu et al.[11] When mountain tunnel passes through completely weathered granite strata, water and mud inrush is easy to occur, causing casualties and economic losses. Grouting is a common and effective treatment method for water and mud inrush disaster. The current existing researches focus on theoretical analysis, numerical simulation, and laboratory test, and the researches based on the field of engineering application are few. Based on the fully weathered granite tunnel of Junchang tunnel in Guangxi, this paper studies the grouting treatment of water and mud disaster in the fully weathered granite tunnel. This paper first introduces the geological and hydrological conditions of Junchang tunnel in order to understand the causes of water inrush and mud inrush. Then, the treatment method of full-section curtain grouting is introduced. During the grouting, the combination of exploration and injection is adopted. According to different hydrological conditions, different kinds of grouting materials are adopted. After grouting is completed, Transient Electromagnetic Methods, water inflow analysis, borehole investigation, and P-Q-T method are used to evaluate the grouting effect. According to the reaction of the detection results, the weak part of grouting can be supplemented to improve the grouting quality. The results show that the curtain grouting is effective for the treatment of water-mud inrush disaster in the fully weathered granite tunnel. This study provides a reference for the treatment of water and mud inrush in other similar tunnels.

Helmut Wannenmacher et al.[12] The Semmering Base Tunnel (SBT), with a total length of 27.3 km, is one of the leading construction projects of the Baltic-Adriatic Railway Network. The tunnel connects the two federal provinces of Lower Austria and Styria and cuts through the eastern part of the Alps. The construction lot SBT 1.1-Tunnel Gloggnitz is characterized by a complex geological- and hydro-geological architecture containing alternating competent geological structures, major fault zones, and corresponding geological transition zones. There are three main water-bearing formations at the construction lot SBT 1.1: (a) Karst-prone blocky limestone with an initial water pressure of 10 bar. The discontinuities form a highly permeable interconnected joint network with a significant storage coefficient of the groundwater table. (b) Massive to blocky dolomite with an initial water pressure of 25 bar. The systematic discontinuities and disturbed zones of subsidiary structures with karst form a permeable, interconnected joint network. (c) The transition zone of the limestone to base structure marks the most challenging area for consolidation- and sealing grouting. Weak fault rocks characterize transition zones with intense fracturing.

However, as subjected to high groundwater pressure of 10 bar, these zones are associated with the potential of flowing ground conditions. Based on the overall project requirements, specific drilling- and grouting methods and materials for pre-excavation grouting have been established and successfully implemented in the construction process. The innovations include a Standpipe-Packer substituting a conventional steel standpipe, a specifically cased drilling system with grouting inserts to prevent erosion within the borehole and allow for defined grouting. In addition, this Grouting-Pipe system replaces standard tube-à-manchettes and controls the flushing while drilling with preventers. Finally, a combined cement-polyurethane grout mix (Hybrid Grout) was implemented to stabilize the grout. The implementation of these measures will be discussed in detail, and their benefits to the construction process will be highlighted.

Xuewei Liu et al.[13] Grouting is a widely applied technique for reinforcing fractured zones in deep soft rock tunnels. By infiltrating rock fissures, slurry materials enhance structural integrity and improve the overall stability of the surrounding rock. The performance of grouting is primarily governed by the flow behavior and diffusion extent of the slurry. This review considers recent advances in the theory and methodology of slurry flow and diffusion in fractured rock. It examines commonly used grout materials, including cement-based, chemical, and composite formulations, each offering distinct advantages for specific geological conditions. The mechanisms of reinforcement vary significantly across materials, requiring tailored application strategies. The rheological properties of grouting slurries, particularly cement-based types, have been widely modeled using classical constitutive approaches. However, the influence of time- and space-dependent viscosity evolution on slurry behavior remains underexplored. Experimental studies have provided valuable insights into slurry diffusion, yet further research is needed to capture real-time behavior under multi-scale and multi-physics coupling conditions. Similarly, current numerical simulations are largely limited to twoand three-dimensional models of single-fracture flow. These models often neglect the complexity of fracture networks and geological heterogeneity, highlighting a need for more realistic and integrated simulation frameworks. Future research should focus on: (1) fine-scale modeling of slurry hydration and mechanical reinforcement processes; (2) cross-scale analysis of slurry flow under coupled thermal, hydraulic, and mechanical fields; and (3) development of realtime, three-dimensional dynamic simulation tools to capture the full grouting process. These efforts will strengthen the theoretical foundation and practical effectiveness of grouting in complex underground environments.

Bolin Jiang et al.[14] With rapid infrastructure development worldwide, the generation of industrial solid waste (ISW) has substantially increased, causing resource wastage and environmental pollution. Meanwhile, tunnel engineering requires large quantities of grouting material for ground treatment and consolidation. Using ISW as a component in tunnel grouts provides a sustainable solution to both issues. This paper presented a comprehensive review of the recent advancements in tunnel grouting materials using ISW, focusing on their feasibility, mechanical characteristics, and future development directions. Initially, the concept and classification of ISW were introduced, examining its feasibility and advantages as grouting materials in tunnels. Subsequently, various performances of ISW in tunnel grouting materials were summarized to explore the factors influencing mechanical strength, fluidity, durability, and microstructure characteristics. Simultaneously, this review analyzed current research trends and outlines future development directions. Major challenges, including quality assurance, environmental risks, and lack of standardized specifications, are discussed. Future research directions, including multifunctional grouts, integrated waste utilization, and advanced characterization techniques, are suggested to further advance this field. These findings provided useful insights for the continued development of high-performance and environmentally friendly ISW-based grouting materials.

Ulrike Pelz et al.[15] Spray-applied waterproofing membranes have received a lot of press and attention in recent years, but the coverage has in large either been design focussed or driven by the material suppliers of such membranes or opponents of the approach. This paper aims to provide a comprehensive overview of the limitations and advantages of spray-applied waterproofing membranes from a practical construction perspective. It discusses the logistic benefits compared to traditional sheet membranes, but also highlights the hidden complexities and impacting factors that are often not fully transparent. The paper covers activities that need to be considered when scheduling or costing such works and provides a general basis for the preparation of Work Method Statements. It also covers contractual constraints, requirements under current international and national standards and regulations, pre-production trials, and quality testing requirements. OH&M considerations are also addressed. Additionally, the paper identifies complementary tasks that are often overlooked but are necessary for a successful membrane installation. These tasks include pre-production trials and quality testing requirements, as well as other activities that need to be considered when choosing a sprayed waterproofing solution. The paper concludes by summarizing the requirements stated by different material manufacturers. All of this is complemented by the authors own experience and observations, and a summary of the consequences drawn from the reviewed data. Consequently, an overview on the aspects of usage of a sprayed-applied membrane material is presented, which the author hopes will provide some practical guidance for the evaluation of the suitability and application of such a product.

VII. CONCLUSION

The review concludes that the use of crystalline admixtures in contact grouting offers a highly effective method for reducing permeability and enhancing the durability of tunnel linings. Experimental studies demonstrate that crystalline admixtures chemically interact with the hydration products of cement to form insoluble crystals that fill capillary voids and microcracks, thereby creating a dense, water-resistant matrix. The permeability reduction achieved through crystalline grouting significantly improves the waterproofing efficiency and minimizes leakage issues in underground structures. Furthermore, the self-healing properties of crystalline materials contribute to long-term maintenance-free performance, even under fluctuating moisture conditions. Overall, crystalline admixture–based grouting represents a sustainable, cost-efficient, and technically robust solution for modern tunneling applications, particularly in challenging geotechnical environments where water ingress control is critical.

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