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Evaluation Of Water Quality Impact (Water Curing) on the Compressive Strength of Bridge Bearing Non-Shrink Grout

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Abstract

Bridge bearings, crucial for connecting superstructures and substructures, rely on grouting to establish stability. This study investigates the impact of water quality on the compressive strength of non-shrink grout in bridge bearings. Cube tests, employing Fosroc Conbextra grout, were conducted to explore the effects of various water sources on both early and long-term strength. The goal is to enhance the durability of non-shrink grout by providing guidance on optimal water source selection. Grout cube specimens underwent curing in tap water, rainwater, river water, and wastewater and the water quality tests covered parameters such as appearance, temperature, pH, Total Dissolved Solids (TDS), salinity, conductivity, and Dissolved Oxygen (DO). Tap water and rainwater consistently demonstrated strength. Standard deviation analysis favored the reliability of rainwater over time compared to river water and wastewater. Despite its strength, tap water exhibited increased deviation from 7 to 28 days. This study emphasizes the crucial role of water quality in optimizing material performance, highlighting tap water for consistent strength and rainwater for reliability. Consideration of both strength and consistency is essential when selecting water curing methods for optimal material performance in construction and engineering.

Keywords: Non-shrink grout, Water curing, Water quality, Compressive strength, Bridge bearings, Optimization practices.

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1. Introduction

Bridges are essential for transportation, ensuring connectivity and safe movement of people and goods (Richard & Sobanjo, 2021). The structural integrity of bridges relies on components like bridge bearings, crucial for supporting superstructure weight and accommodating movements caused by loads and thermal expansion (Mahajan, 2023). This research focuses on assessing the compressive strength of grouting cement-based materials used in bridge bearings and examines the impact of water quality during the curing process. Bridge bearings act as interfaces between superstructures and substructures, transferring loads and allowing for movements. Grouting, a common practice, involves using non-shrink grout to create a stable connection between bearings and pedestals (Shaheen et al, 2017). Compressive strength of the grout is vital for bearing load capacity, with curing playing a key role. The quality of curing water, including composition, temperature, and source, influences hydration and overall grout performance (da Rocha Gomes et al., 2023). Proper curing is crucial for achieving design compressive strength and durability (Y. Bhattarai et al, 2024). Different water types impact the curing process, affecting hydration reactions in cementitious material (Todaro & Pace, 2022). Limited research exists on water quality's specific impact on grouting cement-based materials under bridge bearings (David et al, 2009). Various water sources (rainwater, tap water, wastewater, river water) are tested, mirroring potential options for bridge construction. Water quality variations can affect non-shrink grout properties, making it essential to investigate their influence on grout strength, setting time, and long-term performance in bridge bearing applications. This research addresses the knowledge gap by evaluating how water quality in the curing process influences the compressive strength of grouting materials in bridge bearings, providing critical insights into their relationship.

2. Literature Review

In this section, an overview of Non-Shrink Grout for bridge bearings is provided, delving into its application, specifications, and the influence of water quality on curing and compressive strength. The characteristics of Conbextra Grout and its application in bridge bearings are examined, drawing insights from relevant sources. Additionally, the use of different water sources tap water, rainwater, river water, and wastewater is explored.

2.1. Bridge Bearing Non-Shrink Grout

To ensure the proper functioning and longevity of bridge bearings, the material used for grouting is of utmost importance. Non-shrink grout, a type of high-performance construction material, has gained significant attention for its suitability in bridge bearing applications. Non-shrink grout is a specialized construction material known for its unique properties, making it an ideal choice for critical structural components used in various engineering and infrastructure projects, including those involving pot type bearings like the one in the Light Rail Transit (LRT3) project. Its primary characteristic is minimal shrinkage during the curing process. This characteristic is particularly significant in the context of pot type bearings. These bearings are integral components of various structures, such as bridges, buildings, and rail systems, and they must maintain their initial positioning throughout their lifespan. Any shrinkage in the grout that supports these bearings can lead to misalignment, instability, and, ultimately, structural issues (Heggade, 2013).

2.2. Key Properties of Non-Shrink Grout (NSG)

Non-shrink grout (NSG) is valued for its flowable nature. It can be easily mixed and poured into tight spaces, ensuring complete coverage around the bridge bearings. This flowability allows the grout to fill voids and irregularities in the bearing's seat, ensuring a secure fit. In large-scale projects, ease of installation is paramount, and NSG offers a practical solution, simplifying the process for construction. NSG is often formulated to resist the effects of chemicals, weather, and other environmental factors. This resistance is particularly crucial for infrastructure projects with long lifespans. Over time, exposure to these elements can affect the stability of the bridge bearings and the overall structure. Non-shrink grout’s resistance ensures the long-term stability and durability of these bearings, reducing maintenance and repair costs (Ju et al., 2012). High-quality grout in bridge bearings is expected to comply with industry standards and specifications, such as ASTM C1107. Adherence to these standards ensures consistency, reliability, and safety in construction projects, thereby enhancing the quality and performance of bridge bearings (Li et al., 2023). The key properties of NSG used in bridge bearings are instrumental in ensuring the safety and longevity of bridge structures. These properties, including minimal shrinkage, high compressive strength, flowability, chemical resistance, durability, and adherence to industry standards, underpin the stability, alignment, and structural integrity of bridge bearings.

2.3. Fosroc Conbextra GP Specification

Fosroc Conbextra GP, identified as a type of non-shrink grout, plays a pivotal role in this study focused on construction applications (Fosroc Grouting Solutions, 2020). Specifically designed for grouting and anchoring purposes, Conbextra GP is chosen for its versatility, ease of handling, and adherence to stringent quality standards. The study highlights its significance in supporting heavy machinery or structural elements, emphasizing key attributes such as non-shrink properties, high compressive strength, ease of use, durability, and versatility for a range of projects. In adherence to stringent quality standards outlined in BS EN 1504-3 class R4 and BS EN 1504-6, Conbextra GP is chosen for its reliability. Compressive strength requirements ensure its suitability for various construction and structural applications (Conbextra Gp2, 2021). The study also extends its focus to the transport sector, where Fosroc's Conbextra grouts, address diverse needs in railway and bridge projects (Fosroc Grouting Solutions, 2020). Emphasizing their resistance to chemical attacks, high fluidity, and adaptability to load-bearing demands, these grouts ensure structural integrity, durability, and longevity. The study recognizes Conbextra GP as a specific type of non-shrink grout within the Fosroc Conbextra product range, tailored to meet industry standards and address the challenging conditions of the transportation sector. In this study, Conbextra GP2 was used since it is designed to have plastic shrinkage compensation, making it suitable for applications where dynamic load resistance is required. This characteristic could be beneficial when evaluating the impact of water curing on the compressive strength of bridge bearing non-shrink grout, as the plastic shrinkage compensation may help maintain the grout's integrity under varying conditions (Conbextra Gp2, 2021). Conbextra GP complies to AS 4020-2018 at an exposure level of 15,000mm² per litre; AWQC Report 320823.

2.4. Compressive Strength of Grout Cube Test

In construction, the compressive strength of grout is crucial for stability and safety. This strength is influenced by factors such as mix ratios, curing conditions, and duration (Chee Yan, 2021). Accurate strength measurement relies on proper curing practices, adherence to mix ratios, and understanding cube specimen tolerances (Hamada et al., 2022). To ensure suitability for construction, compliance with BS EN 1504-3 standards is essential. The minimum requirements are 50 N/mm² at 7 days and 60 N/mm² at 28 days (BS EN 12390-3, 2019). Similarly, concrete compressive strength is essential, indicating its ability to withstand compression forces (Rahimi et al., 2023). Factors affecting concrete strength include individual component strengths, material quality, mix proportions, water-cement ratio, curing techniques, and temperature effects (Raju et al., 2020). The compressive strength test, conducted on cubes, provides crucial insights into concrete quality.

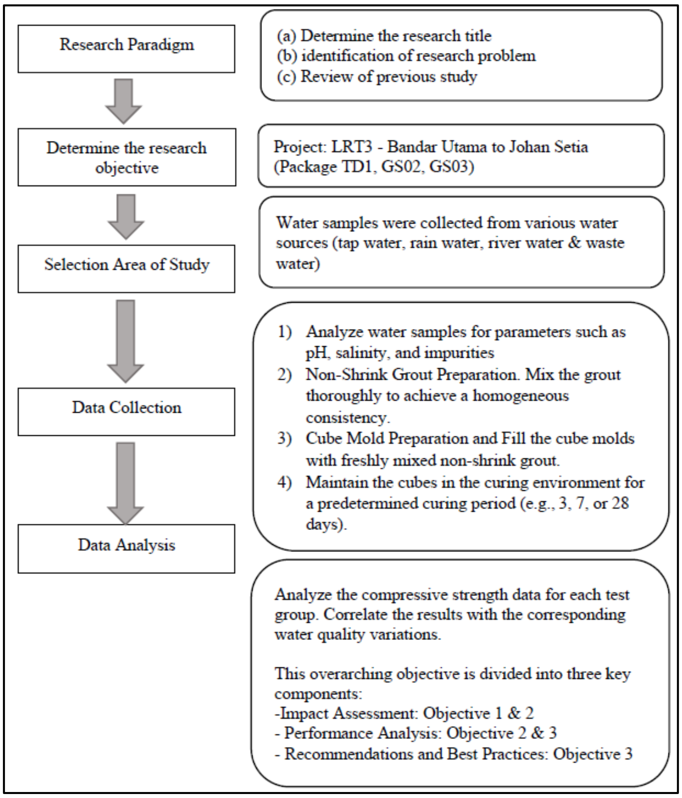
2.5. Influence of Water Quality on Curing Process and Compressive Strength

Water's role in concrete is crucial, affecting workability and hydration. Considering water types, this study evaluates their impact on the compressive strength of bridge bearing non-shrink grout. It aligns with ACI standards, ASTM guidelines, and "Guide to Curing Concrete" (ACI Committee 308, 2016; ASTM C109/C109M, 2011). The research aims to optimize water quality conditions. Water quality scrutiny is vital for concrete, given its impact on strength and durability. Specific criteria for mixing and curing require meticulous scrutiny. Water from various sources, including alternative ones, undergoes testing for potential structural defects. The concrete requires a 28-day curing period for maximum strength, with testing done at the 3rd, 7th, and 28th days (Mohe et al., 2022). Recent advancements in concrete technology, focusing on sustainability, recycled materials, and curing innovations, have been extensively studied (Mohamad et al., 2017; Omidinasab et al., 2022; Assal and Abou-Zeid, 2019; Arooj et al., 2021; Madi et al., 2017; Hasan et al., 2020; Kumar, 2017). While contributing significantly to understanding concrete behavior, a critical gap exists in the literature regarding the specific impact of water curing on the compressive strength of non-shrink grout in bridge bearings. Existing studies explored additives, recycled materials, and water quality but missed addressing the unique challenges of non-shrink grout in bridge applications. This proposed research aims to fill this gap, investigating the distinctive relationship between water curing and the compressive strength of bridge bearing non-shrink grout, tailored to the specific construction context.

3. Methods

Water curing in construction is pivotal for non-shrink grout. The impact of water quality on this process, especially from diverse sources, requires thorough exploration for optimal compressive strength and durability.

This framework in Figure 1 outlines the systematic approach for evaluating the impact of water quality on compressive strength. It visually presents the key steps taken throughout the study.



(a) Determine the research title
(b) identification of research problem
(c) Review of previous study

Project: LRT3 - Bandar Utama to Johan Setia (Package TD1, GS02, GS03)

Water samples were collected from various water sources (tap water, rain water, river water & waste water)

1) Analyze water samples for parameters such as pH, salinity, and impurities
2) Non-Shrink Grout Preparation. Mix the grout thoroughly to achieve a homogeneous consistency.
3) Cube Mold Preparation and Fill the cube molds with freshly mixed non-shrink grout.
4) Maintain the cubes in the curing environment for a predetermined curing period (e.g., 3, 7, or 28 days).

Analyze the compressive strength data for each test group. Correlate the results with the corresponding water quality variations.

This overarching objective is divided into three key components:
-Impact Assessment: Objective 1 & 2
- Performance Analysis: Objective 2 & 3
- Recommendations and Best Practices: Objective 3

Figure 1. Research Framework of the Study

3.1. Water Source Sampling

Water source sampling for the study on the relationship between water quality and non-shrink grout compressive strength involved tap water, river water from Bukit Lagong (using water grab sampling), rainwater from Shah Alam, and wastewater from a nearby commercial area. Tap water was a crucial reference, considering its common use in urban construction. Bukit Lagong served as a reference for local environmental conditions. Rainwater addressed precipitation effects on outdoor construction, while wastewater sampling aimed to identify potential contaminants. This diverse approach provides nuanced insights into the impact of different water sources on grout strength, relevant to real-world bridge construction scenarios.

3.2. Cube Grout Preparation

The study employs Fosroc Conbextra grout, adhering to the specific mixing ratio of 4.5 liters of clean water per 25kg bag of grout. This ratio is meticulously measured to accurately represent field conditions. The mixing procedure is according to the Fosroc Conbextra Cementitious Grouts Application Guide (2020) also stated packaging of the grout as shown in Figure 2. Correct mixing of the grout involves the gradual addition of grout powder to measured water, utilizing a low-speed mixer to achieve a homogeneous, lump-free consistency. Mixing time has ben monitored to ensure sufficient time for the additives to begin working to produce the required final product in the range of 3 to 5 minutes once all the powder has been added.

After the prepared mixing grout, then pour it into Cube molds size 100 x 100 x100mm, meeting the standards of BS EN 12390-1:2021, were cleaned and coated with mold release agent. Demoulding was conducted 24 hours after casting (Figure 3) and to be cured in water tank for 7 and 28 days (Figure 4). The expanded methodology introduced variations by curing cubes in different water sources (tap water, rainwater, river water, and wastewater).

Figure 2. Grout Mixing Preparation using Fosroc Conbextra

Figure 3. Cube molding and Demolding

Figure 4. Water curing process (7 & 28 days)

3.3. Water Quality Testing

In the investigation of water quality impact on the compressive strength of bridge bearing non-shrink grout, a thorough analysis of various parameters was conducted to discern potential influences on the curing process. The parameters considered for measurement included appearance, temperature, pH level, Total Dissolved Solids (TDS), Salinity, Conductivity, and Dissolved Oxygen (DO). About 5 samples were tested for each parameters

3.4. Non-Shrink Grout Cube Test

Adhering to BS EN 12390-1, cube specimens' shape, dimensions, and tolerances are crucial. These studies have a square cross section with sides of 100 mm. Deviations from the prescribed tolerances or irregularities are thoroughly examined. Tolerance checks, ensure consistency and accuracy in testing conditions. If discrepancies occur, they are documented and addressed. Each cube is labelled with casting date and been cured in water tank with various type of water sources according to BS EN 12390-2.


(a) (b)

Figure 5. (a) Testing Cube Machine, (b) Placement of the cube in the testing machine

After the curing period, cubes undergo compressive strength testing was undertaken after 7 and 28 days using a compression machine according to the standard of BS EN 12390-3 as shown in Figure 5. Place the cube centrally on the lower platen of the compression testing machine and ensure that the load will be applied perpendicular to the casting direction. Next, apply the compressive force at a constant rate within the range of 0.6 MPa/s to 1.2 MPa/s. Continue applying the load until the specimen fails, and record the maximum load achieved. Theoretically, the compressive strength, *fc* in unit of MPa can be calculated from the simple formula of $f_c = \frac{F}{A}$, where F is maximum load at failure (N) and A is cross-sectional area of the cube (mm²). The maximum load at failure and precise cube measurements are recorded for subsequent compressive strength analysis.

4. Results and Discussion

The water quality analysis, aimed at evaluating the suitability of water used in the curing process, was conducted on four distinct samples: tap water, rainwater, river water, and wastewater. The results, summarized in Table 1, provide essential insights into the pH, temperature, total dissolved solids (TDS), dissolved oxygen (DO), conductivity, and salinity of each sample. Table 2 displays the results from the cube tests, highlight the compressive strength of cube specimens cured in different water samples.

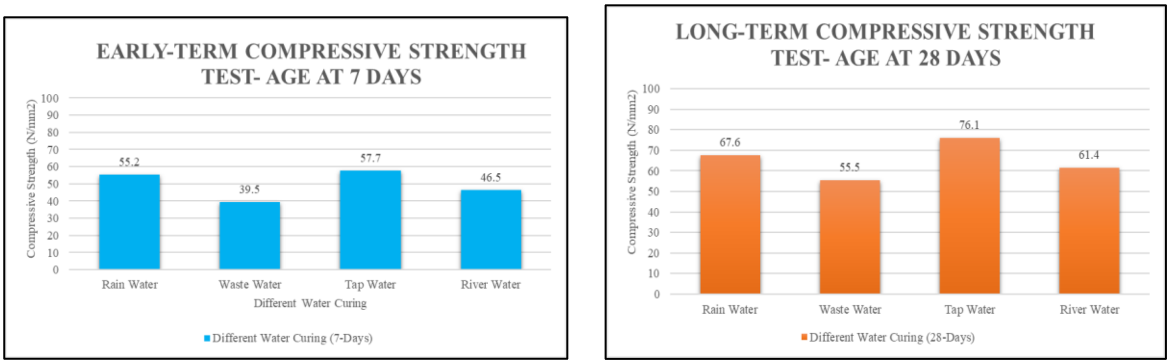
Table 1. Characteristics of Water Sample from Various Source

S/N	Parameters	Unit	Average value concentration				National Water Quality Standards (Malaysia)
			Tap Water	Rain Water	River Water	Waste Water	Class I
1	Appearance		Clear	Clear	Fairly Clear	Brown	-
2	Temperature	°C	25.0	25.0	25.3	25.0	-
3	pH		6.81	7.15	7.33	5.95	6.5-8.5
4	TDS)	mg/L	34.0	52.8	139.7	2250.0	500
5	DO	mg/L	3.78	4.00	3.91	0.79	7
6	Conductivity	µS/cm	67.7	105.4	278.0	4.50	1000
7	Salinity	ppt	0.00	0.00	0.100	2.40	0.5

Table 2. Test Results on Cube Specimen (Compressive Strength)

Age at Test (Days)	Type of Water Curing	Max. Load (kN) at Failure			Average Max. Load (kN) at Failure	Compression Strength to nearest 0.1 N/mm^2	Standard Deviation σ
		Cube 1	Cube 2	Cube 3			
3	-	550.8	543.7	549.1	547.6	54.8	
7	Rain Water	563.8	537.5	554.5	551.9	55.2	1.3203
7	Waste Water	332.8	471.5	380.8	395.0	39.5	7.0599
7	Tap Water	594.1	564.4	571.1	576.5	57.7	1.5695
7	River Water	392.0	508.0	494.4	464.8	46.5	6.3319
28	Rain Water	681.0	680.5	659.1	675.5	67.6	1.2701
28	Waste Water	579.7	560.5	524.8	555.0	55.5	2.7934
28	Tap Water	799.7	705.0	777.1	760.6	76.1	4.9561
28	River Water	593.0	598.1	650.6	613.9	61.4	3.2140

Figure 6 (a)(b) shows the noteworthy findings include tap water yielding the highest strength at both 7 and 28 days, while wastewater results in the weakest material. Notable findings include tap water yielding the highest strength at both 7 and 28 days, achieving 57.7 N/mm² and 76.1 N/mm², respectively. Rainwater consistently provides substantial strength, with 55.2 N/mm² at 7 days and 67.6 N/mm² at 28 days. River water demonstrates improvement, reaching 46.5 N/mm² at 7 days and 61.4 N/mm² at 28 days, while wastewater, although initially weaker at 39.5 N/mm², exhibits increased reliability over time.



(a) (b)

Figure 6. (a) Grout Compressive strength (7-Days), (b) Grout Compressive strength (28-Days)

The reliability of water curing methods at different ages was assessed based on maximum load at failure, average maximum load, compression strength, and standard deviation, as shown in Figure 7. At 3 days, results were consistent around 550-550.8 kN. At 7 days, rain water showed stability (standard deviation 1.3203), while Waste Water exhibited high variability (standard deviation 7.0599). Tap water and river water at 7 days displayed better consistency (standard deviations of 1.5695 and 6.3319, respectively). At 28 days, rain water maintained consistency (standard deviation 1.2701), but waste water, tap water, and river water had higher variability (standard deviations of 2.7934, 4.9561, and 3.2140, respectively). In summary, tap water and rain rater provided more reliable and consistent results, emphasizing the importance of careful water curing selection for concrete strength testing.

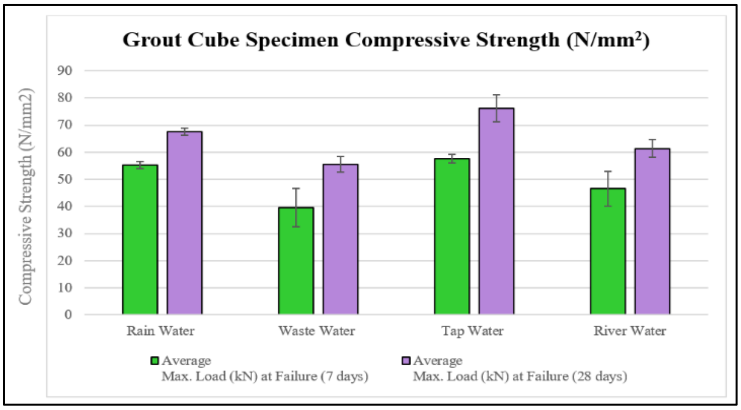
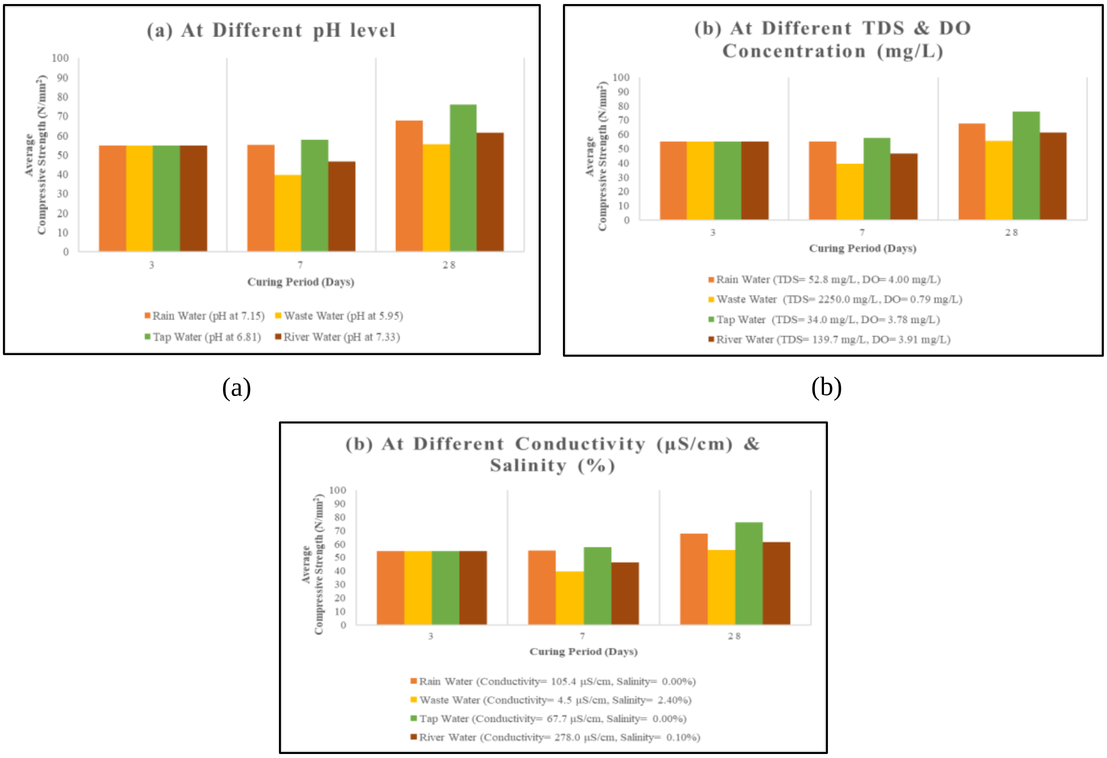


Figure 7. Grout Compressive Strength with Std. Deviation Pattern

Specifically, pH levels in rainwater, tap water, river water, and wastewater were studied, aligning with Malaysia's standards (6.5-8.5). Results in Figure 8(a) indicate that rainwater with a pH of 7.15 fosters efficient cement hydration, leading to enhanced grout strength (John & Lothenbach, 2023). Conversely, acidic wastewater (pH 5.95) hindered hydration, resulting in lower strength. Neutral to slightly alkaline tap water (pH 6.81) excelled in strength development, supporting the expected pH range benefits. River water (pH 7.33) also exhibited respectable strength. These findings emphasize the critical role of water pH in grout strength and suggest optimizing curing strategies based on local water characteristics for durable concrete structures in construction projects.

TDS and DO concentrations notably influence grout strength, as illustrated in Figure 8(b). The values obtained from the table highlight the impact of water quality on grout strength. Rainwater, characterized by low TDS (52.8 mg/L) and high DO (4.00 mg/L), exhibited increased strength. In contrast, wastewater, with elevated TDS (2250.0 mg/L) and low DO (0.79 mg/L), showed a reduction in strength. Tap water, with balanced TDS (34.0 mg/L) and DO (3.78 mg/L), resulted in a significant improvement in grout strength. River water, with intermediate levels of TDS (139.7 mg/L) and DO (3.91 mg/L), displayed a modest increase in strength. In summary, the water quality parameters play a crucial role in optimizing grout performance for durable concrete structures.

Figure 8(c) delves into the impact of conductivity and salinity on grout strength, utilizing water types with specified values based on Malaysia's National Water Quality Standards. Rainwater, boasting a conductivity of 105.4 µS/cm and zero salinity, exhibits a noteworthy increase in compressive strength over time (55.2 N/mm² at 7 days, 67.6 N/mm² at 28 days). Tap water, characterized by a conductivity of 67.7 µS/cm and no salinity, showcases robust strength (57.7 N/mm² at 7 days, 76.1 N/mm² at 28 days). River water, featuring higher conductivity (278.0 µS/cm) and low salinity (0.100%), demonstrates reasonable strength. Despite wastewater's low conductivity (4.50 µS/cm), it displays competitive strength (39.5 N/mm² at 7 days, 55.5 N/mm² at 28 days) due to elevated salinity (2.40%). These findings underscore the significance of considering both conductivity and salinity as pivotal factors influencing grout performance.



(a) (b)

(c)

Figure 8. (a) Grout Compressive strength at Different pH level, (b) Grout Compressive strength at Different TDS and DO concentration, (c) Grout Compressive strength at Different Conductivity and Salinity Level

pH is the primary factor influencing grout strength in water quality analysis. Alkaline rainwater (pH 7.15) exhibits strong compressive strength, while acidic wastewater (pH 5.95) shows lower strength due to its impact on cement hydration. The gathered results confirms this trend, with alkaline rainwater consistently increasing compressive strength over time, and acidic wastewater displaying a noticeable decrease. Tap water and river water, within or close to the recommended pH range, consistently show steady and robust compressive strength development. Other parameters like Total Dissolved Solids (TDS), Dissolved Oxygen (DO), conductivity, and salinity, though important, do not exert as pronounced an influence on grout strength. Their variations in different water types do not consistently correlate with grout strength deviations, highlighting the specificity of pH in dictating the efficacy of the cement hydration process and, consequently, grout strength.

5. Discussion and Implications

The water quality analysis aimed at assessing the suitability of water for the curing process revealed significant insights into the influence of various water characteristics on concrete grout compressive strength. Notably, pH emerged as the primary factor dictating grout strength, with alkaline rainwater consistently exhibiting strong compressive strength and acidic wastewater hindering hydration. Tap water and river water, within or near the recommended pH range, demonstrated steady and robust strength development. Total Dissolved Solids (TDS) and Dissolved Oxygen (DO) concentrations were found to notably impact grout strength, with rainwater and tap water showing increased strength and wastewater displaying a reduction. Moreover, conductivity and salinity were identified as pivotal factors influencing grout performance, emphasizing their significance in water curing selection. The study underscores the importance of careful consideration in choosing water sources, with tap water and rainwater identified as more reliable options for concrete strength testing. Overall, the findings provide valuable guidance for optimizing curing strategies based on local water characteristics to enhance the durability and strength of concrete structures in construction projects.

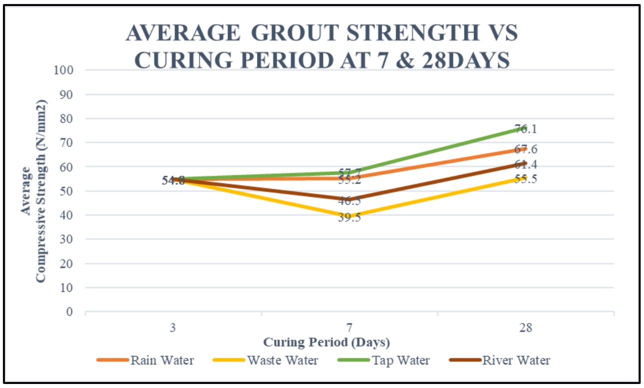


Figure 9. Comparison of average grout strength at different water curing used

Illustrated in Figure 9, tap water consistently emerges as the preferred option, displaying the highest average maximum loads, while rainwater is identified as a viable alternative meeting strength requirements (Figure 9). The recommendation to extend the curing period beyond the conventional 7 days is supported by data showing higher average maximum loads at 28 days for all water types, aligning with existing literature on concrete strength development (Assal and Abou-Zeid, 2019; Mohamad et al., 2017). Emphasis is placed on the importance of stringent quality control measures, involving the monitoring of water quality, curing duration, and environmental conditions (Ojo, 2019). The proposal also addresses environmental concerns by suggesting exploration of water treatment methods to improve the quality of available sources (C.C et al., 2021). Consistency in curing conditions is highlighted as crucial, recognizing the significant impact of variations in temperature and humidity on grout performance. The study recommends seeking expert advice for a dynamic and responsive strategy in optimizing water curing practices. In conclusion, the research not only contributes to non-shrink grout curing optimization but also aligns with and extends insights from previous literature. Despite the absence of specific studies on bridge bearing non-shrink grout, the collaborative and multifaceted approach proposed represents a pioneering effort, advancing understanding and strategies for optimizing grout performance in bridge bearing applications.

6. Conclusion

The research successfully achieved all the research objectives, demonstrating the efficacy of tap water in non-shrink grout applications, especially for critical structures like bridge bearings. The study also suggests rainwater as a sustainable alternative, provided it meets guidelines and undergoes rigorous quality control. Careful consideration of environmental factors, regulations, and infrastructure is crucial when opting for rainwater. While tap water remains the preferred choice, the inclusion of rainwater offers a sustainable alternative, requiring stringent quality control and adherence to guidelines. Based on the study's findings, strategic recommendations include expanding the scope of water samples to include groundwater and well water for a nuanced understanding. Extending the research duration for long-term monitoring, validating findings through field applications, analyzing potential contaminants, conducting cost-benefit analysis, and collaborating with industry stakeholders are suggested to enhance the study's applicability, practical relevance, and impact on non-shrink grout practices in real-world construction scenarios.

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Declaration of Conflicting Interests

All authors declare that they have no conflicts of interest.

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