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A Review on Weather Significantly Impacts Concrete Structures By Influencing Their Durability

***Ansh Raj*[1], *Vinay Kumar Singh Chandrakar*[2]**

**M.Tech. Scholar[1], Assistant Professor[2]

Madhyanchal Professional University, Faculty of engineering & Technology, School of civil engineering Bhopal, M.P., India.**

Abstract

Weather plays a critical role in determining the performance, durability, and longevity of concrete structures. Variations in temperature, humidity, precipitation, and wind conditions significantly influence both the fresh and hardened states of concrete. High temperatures accelerate hydration and moisture loss, leading to rapid setting, shrinkage, and potential cracking, while low temperatures slow down curing and can cause freeze-thaw damage. Excessive rainfall alters the water-cement ratio, weakens surface strength, and leads to scaling, while prolonged exposure to high humidity or aggressive environmental conditions can trigger corrosion of embedded reinforcement and surface deterioration. This review highlights the mechanisms through which different weather parameters impact concrete properties, analyzes their short- and long-term effects, and explores mitigation techniques such as the use of admixtures, optimized curing methods, and protective coatings. Understanding these weather-induced challenges is crucial for engineers and construction professionals to design and maintain resilient concrete structures that meet performance standards under varying climatic conditions.

Key Words:-durability, humidity, precipitation, shrinkage, optimized curing methods, design and maintain

Introduction

Weather plays a critical role in the behavior and performance of concrete, impacting both its fresh and hardened states. In hot weather, high temperatures accelerate the hydration process, causing the concrete to set too quickly. This rapid setting reduces the available working time, making proper placement and compaction difficult. Moreover, increased evaporation rates lead to plastic shrinkage cracks, surface scaling, and a reduction in overall strength and durability due to improper moisture retention during curing. On the other hand, cold weather significantly slows down the hydration reaction, delaying the setting and strength gain of concrete. If temperatures drop below freezing, the mixing water inside the concrete can freeze, expand, and create internal cracks, resulting in a weak and crumbly structure once thawed. Rainfall during mixing, placement, or early curing stages can dilute the water-cement ratio, wash away fine particles, and compromise the surface finish, which negatively impacts both strength and durability. Similarly, strong winds during or after placement accelerate surface moisture loss, causing rapid drying that increases the risk of cracking, erosion, and uneven surface textures. To mitigate these weather-related issues, contractors often implement protective measures such as using retarders in hot conditions, heaters and insulated blankets in cold weather, surface covers during rainfall, and windbreaks to reduce excessive evaporation, ensuring that the concrete achieves its intended strength, durability, and performance over time.Concrete's inherent properties make it exceptionally suitable for construction in regions exposed to extreme weather events due to its high compressive strength, durability, and dense structure, which collectively form a strong barrier against wind, water infiltration, and temperature variations. Its ability to withstand heavy loads and resist deformation under pressure provides structural stability during hurricanes, cyclones, floods, or intense heat waves. By integrating advanced engineering techniques such as high-performance mix designs, supplementary cementations materials, and chemical admixtures, along with the careful selection of aggregates with desired thermal and mechanical properties, concrete can be customized to meet specific environmental challenges. For example, air-entrained concrete enhances freeze-thaw resistance in cold climates, while low-permeability mixes reduce water ingress in flood-prone or coastal areas, and heat-reflective additives minimize thermal expansion in hot zones. These tailored approaches not only improve the material's longevity and resilience but also reduce maintenance needs and life-cycle costs, making concrete a reliable and adaptable choice for sustainable and weather-resilient infrastructure.

Literature Review

AbhayVerma et al (2023) weather directly affects the strength and setting time of concrete, especially in cold weather conditions. When the temperature drops below 4.5°C, it is categorized as cold weather concreting, which requires special precautions to ensure proper strength development and durability. In such conditions, the hydration process of cement slows down significantly, leading to delayed setting and reduced early strength. To address this, measures such as using warm mixing water, accelerating admixtures, insulated formwork, and proper curing techniques are implemented to maintain the required temperature for effective hydration. In mountainous regions, where temperatures are consistently low, cold weather concreting techniques are essential to prevent freezing of water in the mix, ensure proper setting, and achieve the desired strength and performance of the concrete structure.

Yassir M. Abbas et al (2023) this study analyzed the strength and permeability behavior of binary (silica fume–cement) and ternary (silica fume–fly ash–cement) concrete systems cured for 7, 28, 90, and 180 days under high ambient temperatures (35–45°C), with water-to-binder (w/b) ratios ranging from 0.18 to 0.55. Test results showed that adding 5% silica fume (SF) significantly improved compressive strength after 28 days, whereas 10% and 15% additions showed no notable strength gains. A higher w/b ratio of 0.55 achieved slightly greater strength gains compared to lower ratios (0.16, 0.25, and 0.40). Permeability decreased by 70% when 5% SF was added to concrete with a 0.25 w/b ratio, but higher SF percentages showed only marginal improvements, particularly in mixes with higher w/b ratios (0.40 and 0.55). The ternary SF–fly ash (FA) mixes in ultra-high-performance concrete (UHPC) achieved negligible permeability, demonstrating superior durability. Predictive modeling confirmed high accuracy, with predicted-to-tested strength and permeability ratios between 0.96 and 1.01. Parametric analysis revealed a shift in permeability behavior around 6% SF content, indicating that controlled SF levels enhance performance, while excessive SF may adversely affect permeability.

Rawan Ramadan et al (2022) hot weather concreting poses significant challenges to the mechanical and durability performance of concrete due to accelerated hydration, rapid moisture loss, and increased risk of thermal cracking. Elevated ambient temperatures, low humidity, and high wind speeds during mixing, placing, and curing stages often lead to reduced workability, rapid setting, increased slump loss, and higher water demand. These conditions can adversely impact the compressive, flexural, and tensile strengths of concrete, particularly when proper control measures are not implemented. Additionally, rapid evaporation and thermal gradients contribute to micro cracking, shrinkage, and long-term durability issues, including reduced resistance to chloride penetration, carbonation, and freeze–thaw cycles. This review examines existing research on the influence of hot weather on the mechanical and durability properties of normal, high-performance, and supplementary cementations material (SCM)-based concretes. It also highlights mitigation strategies such as the use of chemical admixtures, cooling techniques, optimized mix designs, and controlled curing methods to enhance performance in hot weather environments. The findings underscore the importance of proper planning, material selection, and temperature management to ensure consistent quality and longevity of concrete structures in hot climatic conditions.

Robert Larsson et al (2021) this study investigates the impact of various weather conditions on the productivity of typical concrete construction tasks, highlighting weather as a critical factor that negatively influences construction efficiency. Using a questionnaire survey based on the Analytical Hierarchical Process (AHP) for pairwise comparisons, responses from 232 experienced practitioners in Swedish concrete construction projects were analyzed. The findings show that precipitation is perceived as the most significant factor affecting productivity, followed by wind and temperature. The reported productivity loss ranges widely from 0% to 100%, depending on the specific work task, type of weather (e.g., rain or snow), and the intensity of these conditions. The study not only supports previous research but also reveals a more complex relationship between weather and productivity, emphasizing that the extent of impact is influenced by multiple variables, including the nature of the task and the severity of weather conditions.

Yong-Soo Lee et al (2012) traditional accelerators, while economical, often compromise workability due to rapid early hydration. This study explored the use of tablet-form accelerators, similar to those in pharmaceuticals or food industries, to address these challenges. The research evaluated mortar setting time, workability over time, early strength for frost resistance, and freeze–thaw durability. Results showed that tablets at 0.5% and 1.0% dosages effectively maintained workability while achieving sufficient early strength to prevent frost damage, making them a practical and efficient solution for cold weather concrete applications.

Khan et al (2009)previous research on the impact of weather on construction productivity has primarily followed two main approaches. The first focuses on an aggregated level, where weather is analyzed alongside other factors such as design quality, labor skills, and management efficiency. While these studies help identify weather as a significant factor, they lack contextual specificity, as they do not differentiate between the impacts of varying conditions like wind intensity, snowfall levels, or temperature extremes. The second stream of research aims to quantify the direct effects of weather on productivity, offering more practical insights that can be applied in project planning and scheduling. However, even in this approach, the understanding of how different types of weather uniquely affect productivity remains limited, highlighting the need for more detailed and context-specific studies.

H. Justnes et al (2008) from SINTEF conducted a study on the rapid repair of an airfield runway in Trondheim, Norway, during cold weather conditions at around **5°C**, with only a **6**-hour repair window between the last and first flights. The repair mortar used was based on Calcium Aluminate Cement (CAC)**,** also known as *CimentFondu*, blended with 12% silica fume to reduce or prevent strength retrogression often associated with CAC systems. To ensure fast setting and early strength gain, the mix incorporated a lithium carbonate accelerator (~0.02%)**,** whilesodium gluconate (~0.05%) was used as a retarder to control the setting time, though **c**itric acidwas also found to work effectively as an alternative. For optimal workability and to maintain a low water-to-cement ratio (w/c**)** withhigh flowability, the team initially tested lignosulfonate-based plasticizers but ultimately selected a polycarboxylate-based superplasticizer due to its superior performance. This carefully optimized combination allowed the CAC mortar to achieve rapid hardening, high early strength, and durability, making it suitable for emergency nighttime runway repairs under cold weather conditions.

Seyed H.A. Bagherizadeh (2006) aimed to evaluate thereliability and advantages of using the concrete maturity method in extremely cold weather conditions**.** This method is founded on the principle that the strength development of concrete is directly related to its curing temperature history, making it a valuable tool for monitoring and controlling quality during construction in cold climates. The research reviewed the concept and technology of the maturity method, conducted field observations, and analyzed its potential benefits. Findings from a case study demonstrated that implementing the maturity method could significantly reduce projectschedules by providing real-time data on in-place concrete strength. This real-time monitoring allowed project managers to make informed and proactive decisions regarding heating and protection measures, ensuring that the concrete achieved the required strength levels under challenging weather conditions. Overall, the study concluded that the maturity method offers a more accurate and efficient approach to quality control in very cold climates, improving both construction efficiency and safety**.**

Lee et al. (2004) applied the maturity method to predict the strength of cold weather concrete and evaluate the effect of insulating materials for quality control. The results showed that the temperature of concrete cylinders covered with insulation was 4.5–6.0°C higher than that of non-insulated cylinders, indicating the effectiveness of insulation in maintaining heat during curing. The study recommended maintaining the maturity of concrete above 96–115°C·D for at least the first 7 days to ensure proper strength development and keeping the temperature of fresh concrete above 10°C immediately after setting to enhance performance in cold weather conditions.

Nicholas J. Carino et al (2002) Cold weather concreting focuses on maintaining proper conditions to ensure the quality and durability of concrete placed in low temperatures. The primary goal is to protect the concrete at early ages from freezing damage, as freezing can severely affect its strength and durability. In many cases, additional protection is required beyond preventing early freezing to ensure the concrete develops adequate strength. This involves maintaining recommended concrete and material temperatures, keeping detailed temperature records, preparing the site before placement, and determining the appropriate duration of the protection period. Proper techniques such as using protective insulating covers, heated enclosures, and controlled curing methods are essential, along with the use of accelerating admixtures to promote strength gain. Guidelines also cover methods to assess in-place strength and the right timing for form removal. References in the report provide supplementary data highlighting the impact of curing temperatures on the strength development of concrete.

Norway et al (2008) a rapid airfield runway repair was conducted in Trondheim, Norway, during cold weather conditions at 5°C, within a limited six-hour window between flights. The repair used a CAC mortar blended with 12% silica fume to prevent strength retrogression and enhance durability. To achieve rapid setting and hardening suitable for the time constraint, a combination of approximately 0.02% lithium carbonate as an accelerator and 0.05% sodium glucometer as a retarder was employed, with citric acid tested as an alternative retarder. For maintaining a low water-to-cement ratio (w/c) while ensuring high workability and flow ability, a polycarboxylate-based plasticizer was ultimately selected after evaluating lignosulfonate-based admixtures, providing optimal performance for fast and durable runway repair in cold weather.

J. Burgess et al (2020)an innovative heating and monitoring method was successfully implemented for the wintertime casting of the Wabasha Street Bridge in Saint Paul, Minnesota, ensuring quality concrete placement despite extreme cold conditions, with temperatures dropping as low as −28°C (−19°F). The bridge consists of twin 384 m (1,260 ft) box-girder structures sloping 5% from the north side bluffs of the Mississippi River down to the lower part of Saint Paul, featuring two 122 m (400 ft) center spans and two 70 m (230 ft) approach spans, with a deck width of 14.54 m (47 ft 8 in.) accommodating two 3.66 m (12 ft) travel lanes, shoulders, a sidewalk, and barriers. Constructed in balanced cantilever fashion with form travelers, the project team—including the contractor, a local concrete supplier, the city, and the Minnesota Department of Transportation—developed a high-performance concrete mix capable of achieving 24,115 kPa (3,500 psi) compressive strength within 24 hours to allow rapid post-tensioning. Reinforced plastic enclosures around the form travelers housed three 316,761-kJ (300,000-Btu) propane heaters to maintain optimal curing conditions, while the deck surface was covered with plastic and double insulating blankets. Thermocouples embedded in the concrete segments continuously monitored internal temperatures, ensuring the top slab cured above 38°C (100°F) for several days, with the bottom slab and webs maintaining temperatures approximately 11°C higher than ambient conditions. Prior to each pour, forms, reinforcing steel, and previously cast concrete were heated above 10°C (50°F), and the fresh concrete, delivered at about 21°C (70°F), remained above 13°C (55°F) during placement. Propane heaters were operated for five days after each pour, or until the segments achieved a 28-day strength of 41,340 kPa (6,000 psi), while the critical early strength target for post-tensioning was consistently met the day after each pour, even under extreme cold. This efficient heating and monitoring approach limited weather-related delays to just three working days and enabled the bridge to be completed on schedule, demonstrating that segmental cast-in-place construction is a practical and effective solution for major long-span bridges in cold-weather environments.

Koehn et al (1985) have shown that temperature, wind, and precipitation (including snow and rain) are the most significant weather factors affecting construction productivity. Extreme temperatures, whether hot or cold, slow down workers' pace and efficiency, while snowfall adds extra tasks such as covering and uncovering work areas, and high winds can obstruct critical operations like crane lifting, further reducing productivity. Research in this area generally follows two main approaches: one focuses on comparing or ranking various factors, including weather conditions, to evaluate their relative importance on productivity, while the other examines the direct impacts of specific weather conditions on particular construction activities to understand their influence in more detail.

Methodology

The methodology for reviewing the impact of weather on the durability of concrete structures involves a systematic literature review and data analysis approach. First, relevant academic journals, technical reports, and industry standards are identified from reputable databases such as focusing on studies related to temperature variations, humidity, rainfall, wind, and extreme weather conditions. The collected literature is critically analyzed to identify key parameters affecting concrete performance, such as strength, permeability, cracking, and long-term durability. Case studies and experimental data from past research are compared to evaluate the influence of different climatic conditions on concrete behavior. Finally, the findings are synthesized to highlight common trends, gaps in current research, and recommendations for improving concrete mix design, construction practices, and maintenance strategies under varying environmental conditions.

Conclusion

Weather conditions play a critical role in determining the performance and durability of concrete structures. Variations in temperature, humidity, rainfall, and wind significantly influence the fresh and hardened properties of concrete, affecting workability, setting time, strength development, and resistance to deterioration. High temperatures can lead to rapid evaporation, shrinkage, and cracking, while low temperatures slow down hydration and may cause freeze-thaw damage. Excessive humidity or rainfall alters the water-cement ratio and surface quality, and strong winds accelerate moisture loss, increasing the risk of defects. Therefore, adopting appropriate mix design, quality control, protective measures, and maintenance strategies is essential to enhance durability and ensure long-term performance of concrete structures under varying climatic conditions.

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