Water in Concrete Mixture: Role, Proportioning and Effects

Mr. Narayana Gopalakrishnan
Assistant Professor, Department of Civil Engineering, Presidency University, Bangalore, India,
Email Id-gopalakrishnan@presidencyuniversity.in

ABSTRACT:

Concrete's composition, which includes water, has a significant influence on its workability, strength, and durability. This chapter examines the value of water in concrete mixtures and how it affects the material's overall performance. To comprehend their impact on the final qualities of concrete, a number of parameters are evaluated, including the water-cement ratio, water quality, and curing techniques. This research tries to demonstrate the importance of water in obtaining desired tangible features by examining how water interacts with other elements.

KEYWORDS:

Curing Water, Hydration, Water, Washing Aggregates, Water-Cement Ratio, Workability Concrete.

I. INTRODUCTION

The function that water plays in the composition of concrete, as well as in how it performs and behaves overall, is crucial. For concrete to have the appropriate strength, workability, and durability, the right quantity and quality of water are essential. In this article, we will examine the many facets of water's significance in concrete mixtures and comprehend how it impacts the final product's features. We must first acknowledge that concrete is a composite material made up of several ingredients in order to fully understand the relevance of water in concrete. The main components are cement, aggregates, water, and frequently auxiliary components like admixtures [1], [2]. The aggregates are held together by cement acting as a binder, while water serves as the medium for the chemical reaction known as hydration to take place. Cement particles and water molecules interact during the hydration process to create chemical compounds that give concrete its tensile strength and durability. Calcium silicate hydrate (C-S-H) gel is created when water is introduced to cement as a result of a series of intricate chemical processes. The solid matrix that is created by this gel, which fills the spaces between the granules, provides concrete its strength. Water is essential for the hydration process because it creates an environment where the cement particles may react in a positive way.

It serves as a catalyst, speeding up the chemical processes and assuring the development of a solid, dense C-S-H gel. Lack of water can obstruct hydration, leaving weak concrete and insufficiently hydrated cement. On the other hand, too much water can weaken the structure and make it porous by diluting the cement mix [3], [4]. Water not only aids in hydration but also affects the concrete's workability. Concrete's workability is defined as its simplicity in mixing, placing, and compacting without segregation or excessive bleeding. To obtain the correct workability and enable concrete to properly flow and fill the formwork, the proper amount of water must be added. When concrete is sufficiently workable, it may be readily handled during construction, resulting in structures that are uniform and adequately compacted. The water content of concrete must be determined while maintaining a balance, though. Higher water content can improve workability but it can also have a number of negative impacts. The likelihood of segregation, when the coarse aggregates settle and water rises to the surface, increases with an abundance of water, weakening the finished product by interfering with the uniform distribution of aggregates. Additionally, too much water might result in more shrinkage, slower setting periods, and less strength. The resilience of concrete is significantly influenced by water as well. For concrete to reach its full strength and durability potential, proper curing is necessary. Curing entails preserving the ideal humidity and temperature ranges for the concrete to completely hydrate.

Water keeps the concrete wet, preventing moisture from the surface from evaporating, giving hydration time to take place. As a result, the concrete becomes dense and strong. Water also aids in preventing concrete fractures from forming. Due to several reasons including shrinkage, thermal tensions, and external pressures, concrete is prone to cracking. Water prevents early-age cracking and preserves the structure's long-term endurance by preserving the moisture content. Additionally, by lowering the permeability of concrete, hazardous chemicals like chlorides and sulfates are less likely to penetrate the material. water is a crucial component of concrete mixture, contributing significantly to the overall effectiveness and qualities of the final product. It permits the hydration's chemical processes, which lead to the production of a robust and long-lasting matrix. Concrete's workability is influenced by water, ensuring that it can be handled and compacted appropriately. Water is also necessary for the correct curing process, which helps to increase the long-term durability of concrete buildings by avoiding cracking. Engineers and construction experts may use water more effectively and provide better outcomes in building projects by knowing the significance of water in concrete [5], [6].

Workability of Concrete: Concrete's workability is defined as its simplicity in mixing, placing, and compacting without segregation or excessive bleeding. Fresh concrete has this essential quality, which has an impact on how it is handled, placed, and finished during construction. The water quantity, aggregate characteristics, cementitious ingredients, admixtures, and desired consistency of the mixture are all elements that affect how workable concrete is. Achieving the optimum workability is crucial because it guarantees that concrete can flow and fill the formwork correctly, producing structures that are uniform and tightly compacted. The amount of water in concrete greatly affects its capacity to be worked. It takes just the right quantity of water for the combination to flow and be manageable without being too stiff or overly fluid. Lack of water can cause a dry mixture that is challenging to mix and position, resulting in insufficient compaction and brittle concrete.

On the other side, too much water can make the mixture too fluid, which can lead to segregation and bleeding as well as compromise the final product's strength and durability. The workability of concrete is also influenced by the characteristics of aggregates. The flowability of the combination is influenced by the aggregates' size, shape, and grading. By filling up the voids and lowering the need for water, well-graded aggregates with a combination of varied sizes can improve workability. In comparison to angular or rough aggregates, rounded or smooth aggregates offer improved workability since they need less water to reach the necessary consistency [7], [8]. The workability of concrete can be impacted by cementitious materials like cement and supplemental cementitious materials (SCMs) like fly ash or slag. The kind and quantity of cementitious elements affect the mixture's water demand and hydration properties. Certain SCMs can increase workability by enhancing the lubricating between particles and decreasing the need for water when employed in the right amounts. In order to make concrete easier to work with, additives are frequently employed. In order to lower the water content while keeping the necessary consistency, plasticizers or water-reducing admixtures are applied. These admixtures more efficiently distribute cement particles, lowering friction and enhancing the mixture's flowability. Additionally, they can increase the cohesiveness and workability retention of concrete, enabling it to keep its consistency for a longer time.

The particular building application determines the desired consistency of the concrete mixture. For applications where concrete must flow around intricate reinforcing or through crowded spaces, for instance, extremely workable concrete is often needed. On the other hand, vertical parts or constructions with significant formwork pressures may require less pliable or hard concrete. Numerous tests and measures may be carried out to determine the workability of concrete. The slump test is frequently used to evaluate the mixture's consistency and flowability. It entails pouring concrete into a typical slump cone, compacting it, then removing the cone to check the concrete's slump or settlement. To assess workability, additional tests can be run, such as the flow table test or the Vebe test. the handling, placing, and compaction of fresh concrete during construction are all influenced by its workability, a vital property. It is affected by elements such the amount of water present, the characteristics of the aggregate, the cementitious materials, the admixtures, and the desired consistency of the mixture. Having the correct workability makes it possible to arrange, position, and compact concrete with ease, producing constructions that are consistent and well completed [9], [10].

II. DISCUSSION

Water-Cement Ratio: The weight of water to the weight of the cementitious elements and supplemental cementitious materials used in the concrete mixture is represented by the water-cement ratio (w/c ratio), a crucial parameter in the design of concrete mixes. It is a crucial element that has a big impact on how well concrete performs overall and how strong, long-lasting, workable, and durable it is. In order for cement to hydrate, the water-to-cement ratio is very important. Cement particles undergo a chemical process known as hydration when water is introduced, which results in the formation of a binding matrix that keeps the aggregates together. The quality and strength of the final concrete are directly impacted by the water-cement ratio because it controls the quantity of water that is available for hydration. Normal notation for the water-cement ratio is w/c, where w stands for the weight of water and c for the weight of cementitious materials.

For instance, a w/c ratio of 0.5 indicates that 0.5 units of water are required for every unit of cementitious materials. The necessary strength, workability, and durability requirements of the concrete are just a few of the variables that must be taken into consideration when choosing an acceptable water-cement ratio. Generally speaking, a lower water-to-cement ratio increases strength but may also limit workability. In contrast, a greater water-cement ratio may make cement more workable but may also cause it to be weaker and more porous. It is crucial to remember that the ratio of water to cement should not be confused with the amount of water in the entire concrete mixture. The additional water supplied through the moisture content of aggregates or contributed for other purposes, such as admixture needs, is included in the total water content in addition to the water utilized in the w/c ratio.

In order to produce concrete with great strength, a low water-cement ratio is frequently preferred. In addition to ensuring that there is enough water for hydration, it also helps to reduce any surplus water that can weaken the structure. W/C ratios of 0.35 to 0.45 are normal for high-strength concrete compositions. These low ratios contribute to the formation of a compact and dense matrix, which lowers porosity and boosts the overall strength of the concrete. A w/c ratio between 0.45 and 0.60 is frequently utilized for typical concrete applications with moderate strength requirements. This range offers an excellent compromise between workability and strength, making it possible to mix, pour, and compress concrete with ease while yet reaching the desired strength and durability. Higher w/c ratios could be necessary in some circumstances, including when working with highly workable or self-consolidating concrete, to provide the needed flowability and placement ease.

It's crucial to watch out that the concrete's durability and long-term performance are not jeopardized by the increasing water content. It is important to remember that good strength and durability are not necessarily ensured by a low water-to-cement ratio. Achieving the necessary concrete qualities also requires correct compaction, curing, and the utilization of top-notch components. Adequate compaction guarantees that superfluous air gaps are removed, and appropriate curing supplies the moisture required for complete hydration. a key factor in the design of concrete mix that affects the strength, workability, and durability of the concrete is the water-cement ratio. The project's unique needs and balancing elements including strength, workability, and durability determine the selection of an acceptable w/c ratio. Engineers and construction experts can produce concrete mixes that fulfill the specified performance standards by maximizing the water-cement ratio.

Hydration: Concrete undergoes hydration, a chemical reaction between water and cementitious elements like cement. It is an essential step that turns the cement granules into a solid binder, giving the concrete its strength and durability. Hydration, a chain of intricate chemical processes, is started when water is added to cement. Tricalcium silicate (C3S), the primary ingredient in cement, interacts with water to produce calcium hydroxide (CH) and calcium silicate hydrate (C-S-H) gel. The major hydration reaction is another name for this mechanism. Dicalcium silicate (C2S), another important cement ingredient, also hydrates, but more slowly. The cement particles disintegrate and release calcium, silicate, and hydroxide ions when water molecules penetrate their surface during hydration. The C-S-H gel, which fills the spaces between aggregates and holds them together, is subsequently created when these ions mix with water. By forming a tight-knit network, the gel also contributes to the concrete's strength and longevity.

The hydration procedure results in the creation of calcium hydroxide (CH) crystals in addition to the C-S-H gel. Although they are less necessary for the concrete's overall strength, these crystals help make it more long-lasting. Over time, they may combine with atmospheric carbon dioxide to produce calcium carbonate (CaCO3) crystals through a process known as carbonation. This carbonation process aids in preventing corrosion on the implanted reinforcement. Cement hydration is an exothermic reaction, which means it generates heat. Large concrete buildings must take into account the heat produced during hydration, or heat of hydration, since it can affect temperature rise and probable cracking. To regulate the temperature and keep the environment conducive for hydration, proper curing techniques are necessary, such as the application of wet curing or the use of curing agents. The water-cement ratio, temperature, and the presence of admixtures are some of the variables that affect how quickly and how much the material hydrates. In general, a greater water-cement ratio speeds up hydration but may result in increased porosity and decreased strength. On the other hand, a lower water-to-cement ratio decreases hydration while enhancing strength and durability. The pace of hydration is also influenced by temperature, with higher temperatures quickening the process and lower temperatures decreasing it.

The hydration process can be changed by adding combinations like accelerates or retarders. Accelerators hasten the hydration process, enabling quicker setting and early strength growth. They are frequently employed when it is chilly outside or when there has to be a rapid turnaround. Contrarily, retarders prolong the setting period by slowing down hydration, improving workability or placement in hot temperatures. The fact that hydration is a continuous process that lasts long after the concrete has solidified must be remembered. The hydration reaction can go on for a long time, sometimes requiring months or years, which adds to the concrete's long-term strength and durability. the strength and durability of concrete are based on the chemical interaction between water and cementitious ingredients known as hydration. In order to bind the aggregates together and provide them the required qualities for a sturdy and long-lasting structure, it requires the creation of C-S-H gel and other compounds. For concrete mix design, building techniques, and assuring the intended performance of the concrete in diverse applications, it is essential to comprehend the hydration process.

Heat of Hydration: The term heat of hydration describes the heat produced during the chemical process of hydration, in which water combines with cementitious elements (like cement) to create a solid matrix in concrete. The exothermic process is what causes concrete to gradually harden and set. The principal binder in concrete, calcium silicate hydrate (C-S-H) gel, is created when water is introduced to cement as a result of a series of chemical reactions. The heat of hydration, a kind of energy released by these processes, is heat. The behavior and performance of concrete during the setting and early-age curing stages can be significantly impacted by the heat of hydration, making it an important factor to take into account while building with concrete. The kind and quantity of cementitious materials, the water-to-cement ratio, the fineness of the cement, the temperature, and the curing conditions all affect how much heat is produced.

The heat of hydration is greatly influenced by the type of cement that is utilized. The chemical compositions of various cement kinds, such as ordinary Portland cement (OPC), Portland slag cement (PSC), and Portland pozzolana cement (PPC), differ, leading to various heat release properties. In comparison to mixed cements comprising additional cementitious elements like slag or fly ash, OPC typically produces more heat of hydration. The quantity of water to cement and the amount of cementitious ingredients both affect the heat of hydration. A higher cement concentration or a lower water-to-cement ratio may result in more heat being produced. This is because a faster rate of heat release results from the surplus cement particles having more surface area accessible for hydration. The pace and volume of heat emitted during hydration of cement are influenced by its fineness. Greater surface area on finer cement particles speeds up the process and increases heat output. The use of finely milled cement can hasten setting and boost the development of early strength. The heat of hydration is significantly influenced by temperature. A quicker release of heat can occur when the hydration process is accelerated by higher ambient temperatures. In warmer weather, concrete may build up more rapidly because to the heat created, which might make it difficult to work with and place. The heat of hydration, on the other hand, becomes essential in cold weather for preserving the optimum curing temperature and avoiding freezing. Large concrete constructions, mass concrete installations, or concrete with strict temperature restrictions require careful heat of hydration management.

The integrity and durability of the concrete may be compromised by thermal cracking, which is brought on by the high heat produced during hydration. Several tactics may be used to reduce this risk, including the use of low-heat cement, the use of additional cementitious materials, optimizing the water-cement ratio, and the application of sensible cooling techniques throughout the curing process. It is important to keep in mind that while though the heat of hydration is particularly important during the early phases of concrete curing, it may still produce heat for a considerable amount of time, albeit at a decreasing rate. The long-term strength development and general longevity of the concrete can benefit from this residual heat. the heat of hydration is the energy produced when water and cementitious ingredients combine chemically to form concrete. It is affected by variables including cement type, water-to-cement ratio, cement fineness, temperature, and curing circumstances. In order to avoid thermal cracking and to guarantee the best performance and durability of concrete buildings, it is crucial to manage the heat of hydration.

Quality of mixing Water: The performance, durability, and look of the finished concrete product can all be considerably impacted by the quality of the mixing water, making it a crucial consideration in the building of concrete structures. To get the best results, the water used in the concrete mixture must adhere to a set of quality requirements. Consider the following important factors while evaluating the mixing water's quality:

a. **Cleanliness:** The water used to mix concrete needs to be pure and devoid of pollutants such too much organic matter, oils, greases, or other chemicals. Contaminated water can weaken concrete, interfere with the hydration process, or result in surface flaws.

b. **Potable Water:** To ensure the quality and compatibility of the concrete, potable water (drinking water) should ideally be used in the mixing process. Water that is fit to drink and typically devoid of dangerous contaminants is considered potable. Utilizing potable water lessens the chance of contaminating the concrete mixture.

c. **Chloride and sulfate Content:** The mixing water's chloride and sulfate content needs to be within reasonable bounds. Elevated chloride and sulfate concentrations in water can eventually cause concrete to deteriorate and reinforcing to corrode. To avoid potential problems, standards and guidelines set limitations for these ions in mixed water.

d**. pH Level:** The pH level of the water used to mix the concrete should fall within the acceptable range. A pH range of 6 to 8 is often regarded as appropriate. Extreme pH values can have an impact on how concrete hydrates and how stable it is. While very alkaline water might cause efflorescence or problems with the alkali-silica reaction (ASR), acidic water can degrade reinforcement.

e. **Temperature:** The mixing water's temperature might affect the concrete's early strength development and setting time. When using water, it is best to keep the temperature within the advised range, which is normally between 5°C and 35°C (40°F and 95°F). Water that is too hot or cold might interfere with the hydration process and give concrete unwanted qualities.

f. **Alkalinity:** When utilizing admixtures like superplasticizers, the alkalinity of the mixing water should be taken into account. Admixtures may be less or more successful in changing the characteristics of concrete depending on how sensitive they are to levels of high or low alkalinity. It is crucial to adhere to the instructions and suggestions provided by the manufacturer when using admixtures with certain water alkalinity levels.

g. **Consistency:** Throughout the building process, the quality and characteristics of the water used to mix concrete should remain constant. To guarantee that any changes in water quality do not adversely affect the performance of the concrete, any variations in water quality, such as those from various sources, should be carefully assessed and monitored.

It is advised to do routine water testing and analysis to assure the mixing water's purity. Various factors, such as pH, chloride and sulfate content, alkalinity, and other pertinent features, may be tested on water samples in laboratories, which can offer precise information. This aids in seeing any possible problems and addressing them appropriately. Additional treatment or water conditioning methods can be required when the quality of the supplied water falls short of the acceptable criteria. To enhance the quality and usability of water for concrete mixing, water treatment techniques can be used, such as filtration, chemical treatment, or the use of water softeners. In conclusion, a crucial component of concrete building is the quality of the mixing water. The required performance, durability, and aesthetics of the concrete are more likely to be achieved by using clean, drinkable water that adheres to the prescribed limitations for temperature, pH level, and chloride and sulfate content. Maintaining water quality and addressing any possible problems that may occur can be helped by routine water testing and analysis.

Water for Washing Aggregates: The cleanliness, quality, and workability of the aggregates in concrete are greatly influenced by the water used to wash the aggregates. When washing aggregates, undesired materials like dust, dirt, clay, or organic matter that might impact the qualities of the concrete are removed. Aggregate washing normally entails spraying water on the aggregates, followed by the use of mechanical tools like screens or scrubbers to remove contaminants. For the purpose of keeping the required qualities of the finished concrete and avoiding contamination, the quality of water used to wash the aggregates is crucial. The following are some crucial factors to bear in mind while using water to wash concrete aggregates:

a. **Cleanliness:** The water used to wash aggregates needs to be free of impurities that might harm the quality of the aggregates or the concrete. It should also be clean. Contaminated water can introduce foreign substances or chemicals that weaken concrete or change the way it sets and hardens.

b. **Potable Water:** When feasible, it is desirable to wash aggregates in potable (drinking) water. In general, dangerous pollutants and impurities that might affect the concrete are absent from potable water. It aids in preserving the aggregates' quality and integrity, assuring the required performance of the finished concrete product.

c. **Water Quality Testing:** To make sure the water used to wash aggregates satisfies the necessary requirements, it is crucial to routinely test the water quality. Testing may involve determining factors like pH values, chemical composition, the presence of pollutants, and general appropriateness for producing concrete. Regular testing aids in identifying any possible problems or alterations in the water quality that could affect the aggregates or concrete.

d. **Non-Potable Water Considerations:** In some instances, aggregates may be washed using non-potable water sources such recycled water or rainfall. However, the standard and appropriateness of such water sources must be carefully taken into account. Higher concentrations of pollutants, minerals, or compounds that might alter the qualities of concrete may be present in non-potable water. To make sure the water complies with the essential requirements, appropriate filtering or treatment procedures may be required.

e. **Environmental Laws:** It is important to abide by local environmental laws and regulations while washing aggregates with water. The release of tainted water into natural water sources or the environment must be stopped. It may be necessary to install suitable containment and treatment systems to guarantee adherence to environmental regulations.

f. **Water Conservation:** It's critical to utilize water effectively while washing aggregates given the rising emphasis on sustainability and water conservation. Water usage may be decreased while preserving the appropriate level of cleanliness and quality of the aggregates by putting into practice strategies like water recycling and reuse, optimizing spray systems, and limiting water waste.

the water used to wash the concrete aggregates needs to be clear, preferably drinkable, and devoid of any impurities that can impact the characteristics of the concrete aggregates or the finished product. Regular water quality monitoring, observance of environmental laws, and water-saving practices are crucial factors to take into account. The quality, workability, and durability of the concrete can be improved by utilizing the right water when washing the aggregates.

Curing Water: Concrete curing water is the term used to describe the water utilized in the procedure. A critical phase in the production of concrete is curing, which entails creating the right amount of moisture and temperature for the cement to hydrate completely and create the appropriate strength and durability. By preserving the required amounts of moisture in the concrete, water is a key component in the curing process. Applying water to recently installed concrete helps keep moisture from evaporating from the surface, creating an ideal condition for hydration to take place. In order for the cement particles to react and produce the required chemical compounds, including calcium silicate hydrate (C-S-H) gel, which adds to the strength and longevity of the concrete, enough moisture is crucial. The water used for curing should be pure and devoid of any dangerous chemicals that might damage the concrete. Use of water that satisfies the required quality standards or is potable is recommended for the best outcomes. Avoid using water that is contaminated or chemically aggressive since doing so might harm the qualities of the concrete.

Depending on the needs of the project and the site's environment, there are many ways to apply the curing water to the concrete. Common techniques include wet covers, such as wet burlap or plastic sheets, which are laid over the concrete to preserve moisture, sprinkling, where water is sprayed onto the surface at regular intervals, and ponding, where the concrete surface is coated with a continuous water layer. The concrete should not lose moisture due to the chosen curing procedure, and the curing environment should be consistent. The ambient conditions, the concrete mix design, and the intended strength and durability requirements are just a few examples of the variables that affect the curing process and the amount of water used. Depending on the requirements of the project, the normal duration of curing might range from a few days to several weeks. To enable complete hydration and the formation of ideal strength and durability, moisture must be kept in the concrete during this time. On concrete, proper curing with sufficient moisture can have a number of positive impacts. It contributes to lowering shrinkage, minimizing cracking, and improving the structure's overall durability. Concrete that has been cured has increased resilience to a variety of environmental variables, including abrasion, chemical assaults, and freeze-thaw cycles. Additionally, using curing water can help you create a surface finish that is more consistent and visually acceptable. It is important to note that concrete curing should not be confused with concrete's first setting or drying. After the first setting of concrete, when the substance changes from a plastic to a solid state, curing takes place. While drying is the process of removing moisture from the concrete after curing, curing is necessary to provide optimum hydration and the development of strength. In conclusion, curing water is the liquid utilized in the concrete curing process. It contributes to the preservation of moisture in the concrete, creating an ideal environment for hydration and the growth of strength and durability. Concrete constructions perform better overall and have less shrinkage when the curing water and techniques are adequate. In order to achieve the greatest results and long-term functioning of the concrete, certain curing procedures should be followed.

III. CONCLUSION

In the process of making concrete, water plays a crucial role in determining the material's workability, durability, and strength. An excessive or inadequate amount of water can negatively impact the qualities of concrete; hence the water-cement ratio is a crucial aspect in determining how well concrete performs. The quality of the water used should be carefully considered since contaminants or a high mineral concentration might affect how long concrete will last. Additionally, the curing techniques used have a big influence on how concrete hydrates and develops strength. It is feasible to produce concrete with improved qualities by carefully controlling these variables and maintaining an ideal water-cement ratio, which will ultimately result in better building techniques and durable buildings. Engineers and construction workers may make better informed decisions throughout the design and construction phases, resulting in concrete buildings that are more dependable and long-lasting.

REFERENCES

[1] X. Cen, Q. Wang, X. Shi, Y. Su, and J. Qiu, Optimization of concrete mixture design using adaptive surrogate model, Sustain., 2019, doi: 10.3390/su11071991.

[2] M. O. Azeez, S. Ahmad, S. U. Al-Dulaijan, M. Maslehuddin, and A. Abbas Naqvi, Radiation shielding performance of heavy-weight concrete mixtures, Constr. Build. Mater., 2019, doi: 10.1016/j.conbuildmat.2019.07.077.

[3] A. V. Rahul, M. Santhanam, H. Meena, and Z. Ghani, 3D printable concrete: Mixture design and test methods, Cem. Concr. Compos., 2019, doi: 10.1016/j.cemconcomp.2018.12.014.

[4] H. S. Gökçe and Ö. Andiç-Çakır, Bleeding characteristics of high consistency heavyweight concrete mixtures, Constr. Build. Mater., 2019, doi: 10.1016/j.conbuildmat.2018.11.029.

[5] A. H. Albayati and M. H. Abduljabbar, The simulation of short-term aging based on the moisture susceptibility of asphalt concrete mixtures, Results Eng., 2019, doi: 10.1016/j.rineng.2019.100012.

[6] T. S. Rushing et al., Investigation of Concrete Mixtures for Additive Construction, in 3D Concrete Printing Technology, 2019. doi: 10.1016/b978-0-12-815481-6.00007-5.

[7] R. Dhole, M. D. A. Thomas, K. J. Folliard, and T. Drimalas, Chemical and physical sulfate attack on fly ash concrete mixtures, ACI Mater. J., 2019, doi: 10.14359/51716678.

[8] T. B. Montilla, C. A. Mogollón, J. D. A. Gómez, and I. A. Arbolaez, Automotive waste oil as an additive in concrete mixtures: Its use is feasible, Rev. Mater., 2019, doi: 10.1590/s1517-707620190002.0658.

[9] X. Chen, H. Wang, H. Najm, G. Venkiteela, and J. Hencken, Evaluating engineering properties and environmental impact of pervious concrete with fly ash and slag, J. Clean. Prod., 2019, doi: 10.1016/j.jclepro.2019.117714.

[10] B. A. Young, A. Hall, L. Pilon, P. Gupta, and G. Sant, Can the compressive strength of concrete be estimated from knowledge of the mixture proportions?: New insights from statistical analysis and machine learning methods, Cem. Concr. Res., 2019, doi: 10.1016/j.cemconres.2018.09.006.