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Original Article

Influence of Curing with River and Tap Water on the Performance of Various Concrete Slabs

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Abstract - *Concrete is the most important construction material around the world, which is characterized by its strength, durability, and ability to withstand live and dead loads. Concrete consists of three essential components: cement, sand, and gravel, which are mixed with water using different mixing percentages, with the addition of additives to get the required type of concrete. Concrete can be classified into many types according to the required strength demand. In addition, concrete is exposed to dynamic loads, which are the loads that would change the positions and quantities of the concrete structures. The dynamic or kinetic loads often occur in areas exposed to earthquakes and disasters, as well as traffic on highways. The objective of the study is to investigate the effect of curing by tap water and river water on the properties of the concrete. In this study, three types of concrete, which are Normal Concrete (NC), Self-Compacting Concrete (SCC), and Fly Ash Concrete (FAC), were used to form six slabs by using a mold with dimensions of (450*450*100) mm, in addition to their control specimens. Each slab with its control specimens was cured by tap water and river water for 28 days. The slabs were examined for the dynamic load using a drop ball impact device. The results showed that samples cured in river water gave approximately 25% fewer strokes and 16% less crack width than those of samples cured in tap water. The compressive strength of samples cured with tap water was slightly higher than that of samples cured with river water; the average increase was 3%, 5%, and 4.5% for NC, SCC, and FAC, respectively. Also, the results exhibit similar crack patterns with punching failure for all specimens. Using river water for concrete curing is a good option after ensuring that the water is free of pollutants and chemicals that may affect the workability and durability of concrete.*

Keywords - *Concrete Slabs, Drop Ball Impact, Dynamic Loads, River Water, Tap Water.*

1. Introduction

Concrete is a mixture of binder materials (cement) with aggregates mixed together in the presence of water, and sometimes additives are added to the mixture to get some desired properties. When the solid mixture acts with water, the concrete matrix gives off heat, and hence increases the reaction rate due to the increase in temperature. This will result in a strong and homogeneous mass. After that, the curing process of the mixture begins. Curing is a process in which water is applied to the surface of the concrete to lead to moisture in the concrete matrix for producing a strong and stiff structure and preventing cracking [1]. The curing of cement in concrete is accomplished through four stages. First, the surface reactions on the cement particles are produced in conjunction with the release of heat, which continues for 30 minutes. Second, the curing reactions slow down as a result of the formation of the gel layer on the surface of the cement particles, which slows and invalidates the moisturizing for a few hours because the water diffuses in an inhibited manner within the cement particles. Third, the moisturizing process becomes stronger, which continues for approximately 20 hours and is accompanied by hardening of the concrete. Finally, moisturizing continues for many years. For moisturizing continuity, curing of concrete must be done as illustrated in Figure 1. Failure to adequately provide water for concrete curing results not only in low compressive strength but also increases the shrinkage and porosity of the concrete. Concrete may be damaged when exposed alternately to moisture and drying stages [2]. Curing immediately begins in freshly cast concrete, to keep the moisture and control the temperature inside the concrete after the casting stage [3, 4].

Guide to Concrete Construction [4] and Tumpu [5] state that curing affects the main properties of concrete, such as strength after hardening. Hence, drying concrete that is not correctly cured may have only 40% of the strength of the concrete that is properly cured. In addition, the durability of concrete is affected by several factors, such as concrete porosity and absorption. However, pores and capillaries in concrete are directly connected to the water/cement ratios and indirectly to the curing of concrete. For example, when the duration of curing is longer, the concrete porosity is smaller. Curing of concrete offers several advantages: to prevent the concrete from losing the water of cement paste through setting time and through evaporation in the initial days, to minimize the temperature difference inside and outside the concrete, to achieve maximum concrete strength, and to prevent concrete cracking and shrinkage [6].

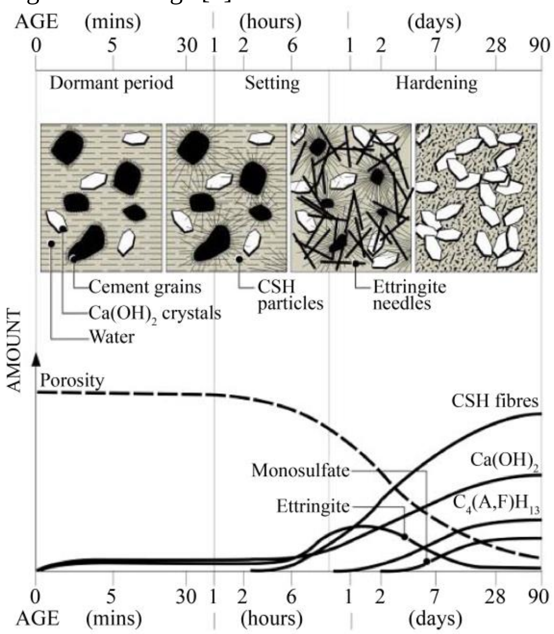


Fig. 1 Schematic representation of hydration reactions of cement and water [4]

There are several ways to cure the concrete, including: water curing, wet covering, formwork curing, continuous spraying, sheet curing, curing by absorbing heat, steam curing, and more [7]. Previous studies indicated that the best one and most effective method is water curing. This type of curing is classified as the most well-known form of concrete curing, especially for small-scale works and for laboratory specimens. It stayed immersed in the whole concrete, in bowls filled with water, for 28 days in most cases. The temperature of water is not exceeded 11 °C, which is colder than the concrete internal temperature to avoid the thermal stresses that lead to shrinkage and cracks of concrete [8]. In recent years, the need for impact-resistant concrete has increased with the increase in damage from accidents and dynamic loading. Concrete is exposed to dynamic loading such as dropping heavy objects onto concrete floors, vibrations from earthquakes, or from heavy traffic on towers, tall buildings, highways, and bridges. These loads can cause deformation and cracks, which are different from those of static loads. Concrete curing process plays an important role in the concrete's ability to withstand dynamic loads, as the chemical reaction of cement compounds contributes to increasing the concrete´s resistance to dynamic loads, where poorly cured concrete is prone to failure [9]. Several studies regarding the structural design of concrete to withstand the kinetic loads in areas exposed to earthquakes and explosions have been done. Stresses are high in kinetic loads and exceed the operating properties. Thus, elastic deformations are exhausted more quickly, leading to a transition to plastic deformations [10]. The high strength must be considered in the concrete design to avoid damage and get high durability [11, 12]. There are limited studies available on the concept of dynamic loads' effect on the behavior of concrete. Therefore, this study focuses on filling the gap in the existing literature on this subject [13]. There are several methods to determine the stability of concrete against dynamic loads, and one of these methods is the drop ball impact test. A drop ball test is a standardized method to evaluate the impact resistance and energy absorption properties of different materials. It consists of dropping a ball of specified weight and diameter from a determined height onto the test specimen. Concrete slab failure is affected by the type of its components in the mix and the drop height [14]. Traditionally, water is used in the concrete during both mixing and curing stages, and a shortage of the required quantity of water during these stages might early stop the hydration process and consequently reduce the compressive strength and increase shrinkages and cracks [15]. Since water demand worldwide is increasing due to the rapid growth in the domestic, commercial, and industrial sectors, and some studies estimate that the construction sector consumes a high percentage of fresh water, it becomes important to consider using alternative water sources for construction purposes. The resistance of concrete in the long term against dynamic loads is affected by inappropriate curing, especially in areas where potable water is in short supply [16]. However, water resource management is considered a challenge, especially where water scarcity is a problem. Consequently, there is a need to seek alternative clean water sources for concrete mixing and curing. Moreover, using treated water for construction purposes is more expensive than using raw water. However, it is necessary to ensure that the quality of water used meets the required standards and does not have a high concentration of chemicals or organics that could negatively affect the concrete properties [17]. The studies show that potable water is used in concrete mixing and curing, and that there are a limited number of studies exploring alternatives to potable water for mixing and curing concrete.

Since concrete curing requires large volumes of water, the use of river water for concrete curing is considered a good option by decreasing the pressure on the potable water supply, lowering overall construction and operational costs, reducing the environmental impact from water treatment processes, long-term preserving the water resources, and enhancing the sustainability concept of the projects, specifically in water-scarce regions. Generally, concrete factories do not aim to reduce water use; rather, they try to find alternatives to potable water, such as river water, groundwater, or even treated wastewater. [18]. The aims of this study are to investigate the effects of concrete curing (by two types of water resources, tap and river water) on the behavior and strength of three types of concrete slabs, which are Normal Concrete (NC), Self-Compacting Concrete (SCC), and Fly Ash Concrete (FAC). In addition, the examination involves the influence of dynamic loads on these concrete slabs. Finally, studying the failure patterns and measuring the crack width of the tested samples (slabs and control specimens) is included in the study.

2. Materials and Methods

The materials selected for this experimental work are illustrated in Table 1, including cement, sand, and gravel to produce traditional Normal Concrete (NC) with 30 MPa of compressive strength (f´c). Silica fume and fly ash were used to produce Self-Compacting Concrete (SCC) with 60 MPa and Fly Ash Concrete (FAC) with 45 MPa, respectively. All the mixtures were mixed with tap water using the percentages shown in Table 1. Glenium 51 was added as a superplasticizer for SCC only to enhance mixture workability for reaching the required compaction. Thus, that process will expel and remove the voids in the mixture, which contributes to improving the strength [19]. The reinforcement of each slab is in the deformed steel bars of diameter 6 mm with a spacing of 85 mm in each direction for the concrete slab mold. The experimental procedure included mixing three types of concrete: NC, SCC, and FAC with mixing percentages of 1:2:3, 1:1.5:2, and 1:2:3, respectively. Fly ash and silica fume were added with a 10% replacement by weight of powder content. Three cubes of 150 mm, three cylinders of 150 x 300 mm, and two prisms of 100 x 100 x 500 mm were cast and tested under a compression device to determine compressive, splitting tensile, and flexural strength, respectively. Two slabs with dimensions of 450 x 450 x 50 mm for NC, SCC, and FAC were cast. The arrangement of steel reinforcement inside the mold and the casted samples are shown in Figure 2. Before testing, tap water was used to cure one of the two slabs of each concrete type with its control specimens for 28 days; however, the second cube was cured in river water. The curing process was performed using the immersion-in-water method.

Fig. 2 Samples of the mold with reinforcement and concrete casting

After the curing stage, the slabs were tested using a drop ball impact test machine, as shown in Figure 3. The drop ball impact device consists of a frame, an arm, and a ball, which were made from iron. The weight of the ball is 1 kg with a fixed drop height of 1 m. The number of strokes for each slab was recorded until the slab sample failed. In addition, the crack width of the failed samples was measured by using the tool illustrated in Figure 4. This type of test is very important for buildings exposed to earthquakes and damage, and highways exposed to moving vehicle loads [10].

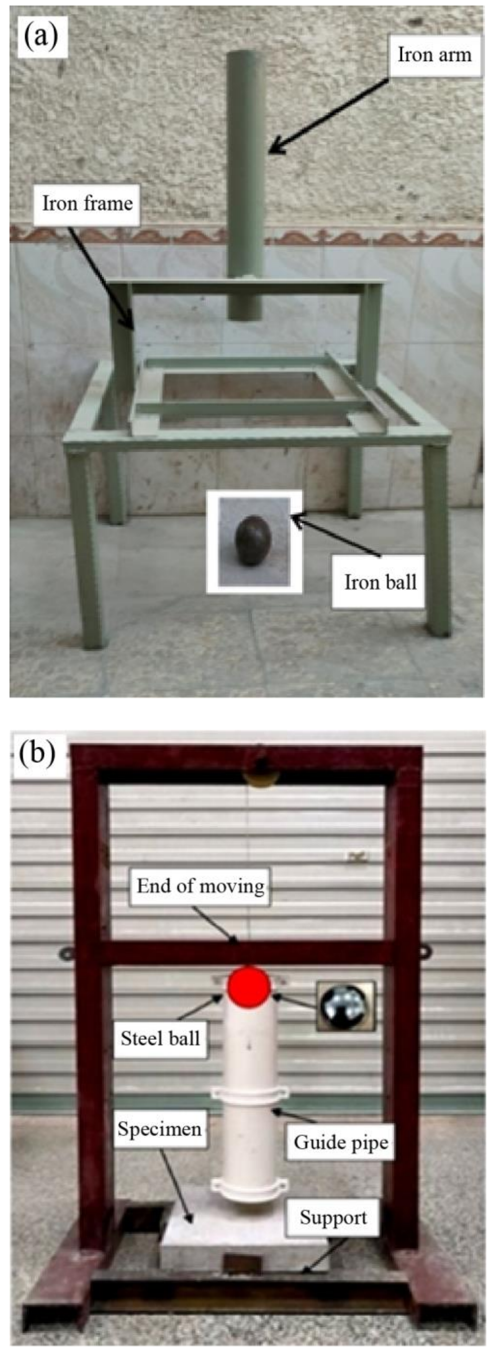


Fig. 3 Drop ball test machine (a) Used in this study, and (b) Reported in the literature [10].

Table 1. Mixing details

	Compressive strength (f'_c) Mpa	Water/powder Percentage (w/p) %	Max. size of aggregate mm	Cement Kg/m^3	Sand Kg/m^3	Gravel Kg/m^3	Water l/m^3	Fly ash Kg/m^3	Silica fume Kg/m^3	Glenium 51 l/m^3
NC	30	0.45	20	350	700	1050	160	-	-	-
SCC	60	0.35	10	360	600	800	140	-	40	15
FAC	45	0.4	10	337	750	1125	150	38	-	-

Fig. 4 Crack width scale

3. Results and Discussion

3.1. Water Analysis

It is important to know the quality and quantity of the water used in the concrete works. In terms of quality, cement hydration and setting time of the concrete may be affected by the water quality. In addition, impurities in the water, such as sulfate and chloride ions, may significantly affect the strength and durability of the concrete and lead to reinforcement corrosion. However, large quantities of water are required for producing and curing the concrete as well as for equipment cleaning. Therefore, knowing the adequate water quantity is essential [20]. For these reasons, seeking different sources of water for construction purposes is crucial. In this study, three of the slabs and their control specimens were cured with tap water, and the other three slabs and their control specimens were cured with river water. River water samples were taken from the Tigris River in Baghdad, Iraq. However, tap water samples were collected from the tap source at the construction laboratory/College of Engineering/Mustansiriyah University, Baghdad, Iraq. River and tap water samples were analyzed at the Research & Technology Center of Environmental, Water & Renewable Energy, Baghdad, Iraq, and the analyzed data are revealed in Table 2.

Table 2. The specification of tap and river water

No.	Parameters	River water	Iraqi River water Standards [21, 22]	Tap water	Iraqi Tap Water Standards [21, 22]
1	pH	7.15	6.5-8.5	7.4	6.5-8.5
2	Total Dissolved Solids, TDS (mg/L)	304	1500 (max)	506	1000 (max)
3	Chloride, Cl^{-1} (mg/L)	105	250 (max)	98	250 (max)
4	Calcium, Ca^{+2} (mg/L)	86	40-100	77	20-200
5	Manganese, Mn^{+4} (mg/L)	BDL	0.1(max)	BDL	0.1(max)
6	Ferrous, Fe^{+3} (mg/L)	0.036	0.3(max)	BDL	0.3(max)
7	Sulfate, SO_4 (mg/L)	290.36	250 (max)	224.4	500 (max)
8	Magnesium, Mg^{+2} (mg/L)	51	50 (max)	42	40 (max)

From Table 2, the pH level were 7.4 for tap water and 7.15 for river water, which were within the standard values. In addition, the percentage differences between tap and river water for the TDS, Cl, SO_4, Ca, and Mn concentrations were 60%, 7%, 23%, 10.5%, and 18%, respectively. Also, the results indicated that the sulfate content of the river water was higher than the Iraqi Standards by 16%. In addition, the concentration of magnesium in tap and river water exceeded the Iraqi Standards by 5% and 2%, respectively. The high concentrations of Cl, SO_4, and Mg indicate that the form of magnesium sulfate ($MgSO_4$) and magnesium chloride ($MgCl_2$) were present in the water. The decomposition of $MgSO_4$ negatively influences the concrete strength and durability. Moreover, increasing $MgCl_2$ content in the curing water reduces the compression and tensile strengths of the ordinary Portland cement concrete. The effects of these compounds lead to the expansion and erosion of concrete. The high concentration of these compounds may first damage the concrete by causing corrosion and surface cracks, retarding the initial setting time, and then the cracks continue through the entire depth of the concrete, resulting in final failure [23, 24]. The water analyses, however, indicated that the concentration of TDS of tap water was higher than that of river water. This is attributed to the processes of conventional water treatment, which include adding chemicals for purification, and it does not consider removing TDS from the treated water by adding a reverse osmosis membrane process, since it is below the standard limit. To conclude, using river water for concrete curing due to its availability, economic consideration, and sometimes its source close to the construction sites makes it more valuable. However, the river water quality must be free from pollutants and materials that could damage the concrete.

3.2. Materials Properties

3.2.1. Cement

The ordinary Portland cement, which was produced by the Mass company, Bazyan, Al-Sulaimaniya, Iraq, was used in this study. Tables 3 and 4 show the chemical composition and the physical properties, respectively, of the used cement.

Table 3. Chemical analysis of the used cement

Constituents	% by weight	IQS/1984 part 5 [25]
Silicon dioxide (SiO_2)	19.45	-
Calcium oxide (CaO)	60.35	-
Magnesium oxide (MgO)	3.21	< 5.0
Ferric oxide (Fe_2O_3)	3.75	-
Aluminum oxide (Al_2O_3)	4.75	-
Sulfur trioxide (SO_3)	1.30	< 2.8
Loss on ignition (LOI)	1.37	< 3.8
Insoluble residue	1.05	< 2
Time saturation factor	0.78	0.66 – 1.02
Main compounds (Bogue´s Compounds) % of cement weight		
Tricalcium Silicate	48.5	-
Dicalcium Silicate	32.35	-
Tricalcium Aluminate	4.8	-
Tetracalcium Aluminoferrite	10.2	-

Table 4. Physical characteristics of the used cement

Physical Characteristics	Experimental value	IQS/1984 part 5 [25]
Compressive strength of cube (70 x 70 x 70) mm cement grout, (MPa) three days seven days	 17 24.45	 > 15 > 23
Fineness (cm^2/g) / Blaine Method	2629	> 2300
Setting time (Vicat´s Experiment) Initial time (min.) Final time (min.)	 156 250	 > 44 min < 11 hrs
Soundness/ (Auto Clave), (%)	0.3	< 0.8

Table 5. Sieve analysis of sand

Max. size (mm)	IQS/1984 part 45 (Zone 2) [27]	Percentage of passing
9.5	100	100
4.75	100	90-100
2.36	90.3	75-100
1.18	78.3	55-90
0.6	55.2	35-59
0.3	21.5	8-30
0.15	6	0-10
Pan	0	-

3.2.2. Aggregates

Aggregates from 60% to 80% of the volume of concrete have the main effects on concrete properties. The aggregates should be clean, hard, durable, and free of impurities such as chemical materials and clay [26]. Sand which was used in this research was taken from the AL-Ukhaider area, Karbalaa, Iraq, with a fineness modulus (F.M) of 2.6. Table 5 shows the sieve analysis of the used sand.

In addition, gravel that was used in this research was taken from AL-Niba´ee Area, AL-Anbar, Iraq, with a maximum size of 20 mm for NC and 10 mm for both SCC and FAC. Table 6 shows the sieve analysis of the used gravel.

Table 6. Sieve analysis of gravel

Max. size (mm)	Percentage of passing	IQS/1984 part 45 [27]
20	100	100
14	100	90-100
10	65.21	50-85
5	4.33	0-10
2.36	0.17	-

3.3. Control Specimens

As mentioned in the materials and methods section, different control specimens of three types of concrete (NC, SCC, and FAC) were cast and cured for 28 days in tap and river water. After that, the compressive, flexural, and splitting tensile strengths of the concrete samples were examined, and the results are shown in Figures 5, 6, and 7.

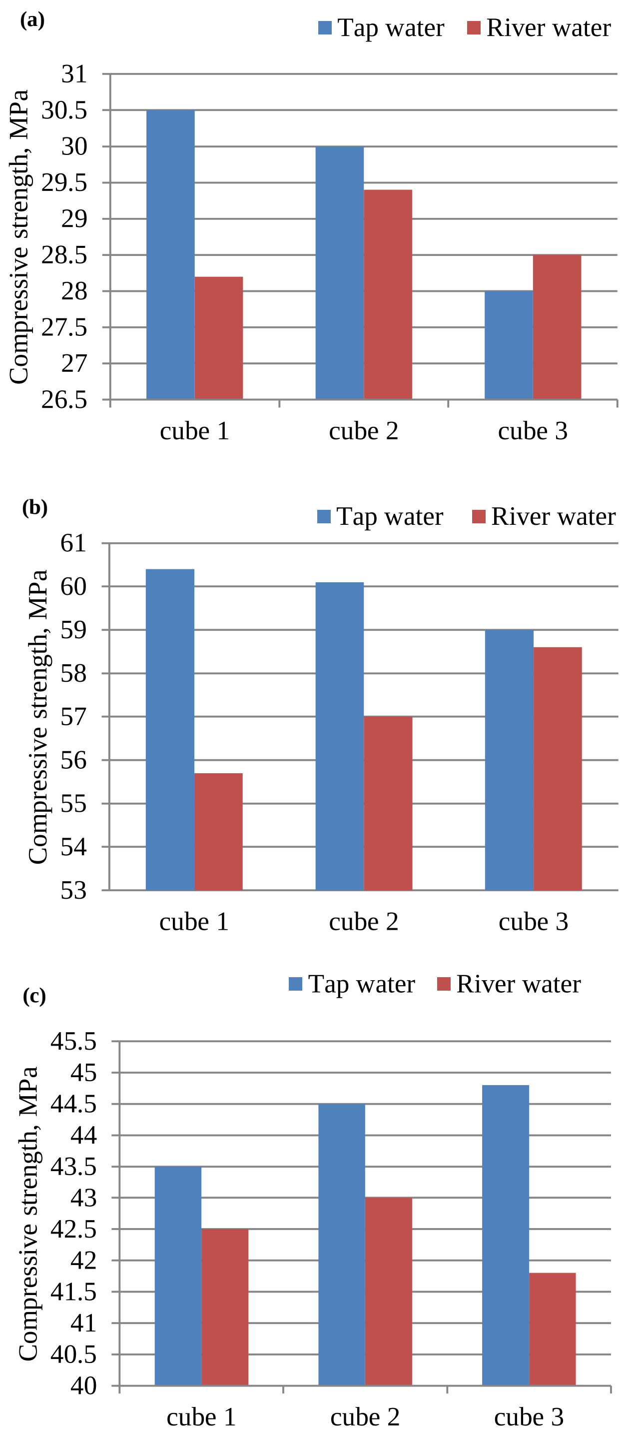


Fig. 5 Compressive strength of control specimens for (a) NC, (b) SCC, and (c) FAC.

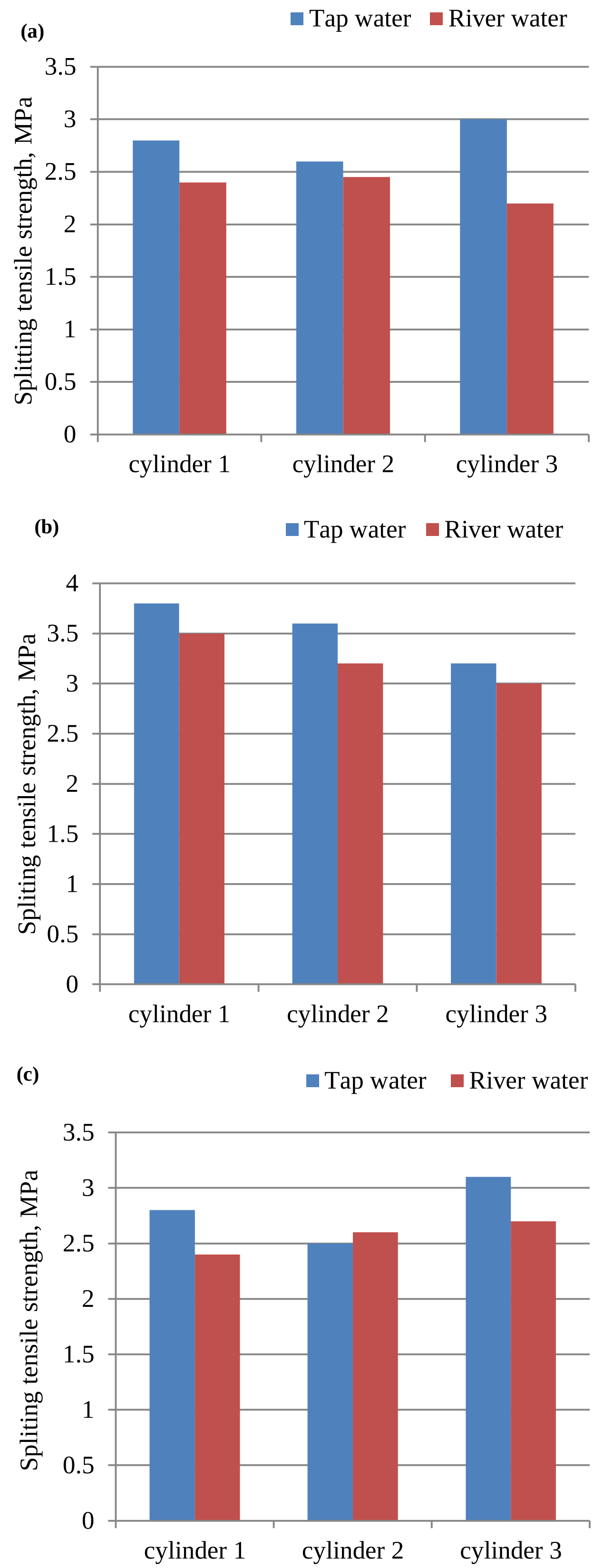


Fig. 6 Splitting tensile strength of control specimens for (a) NC, (b) SCC, and (c) FAC.

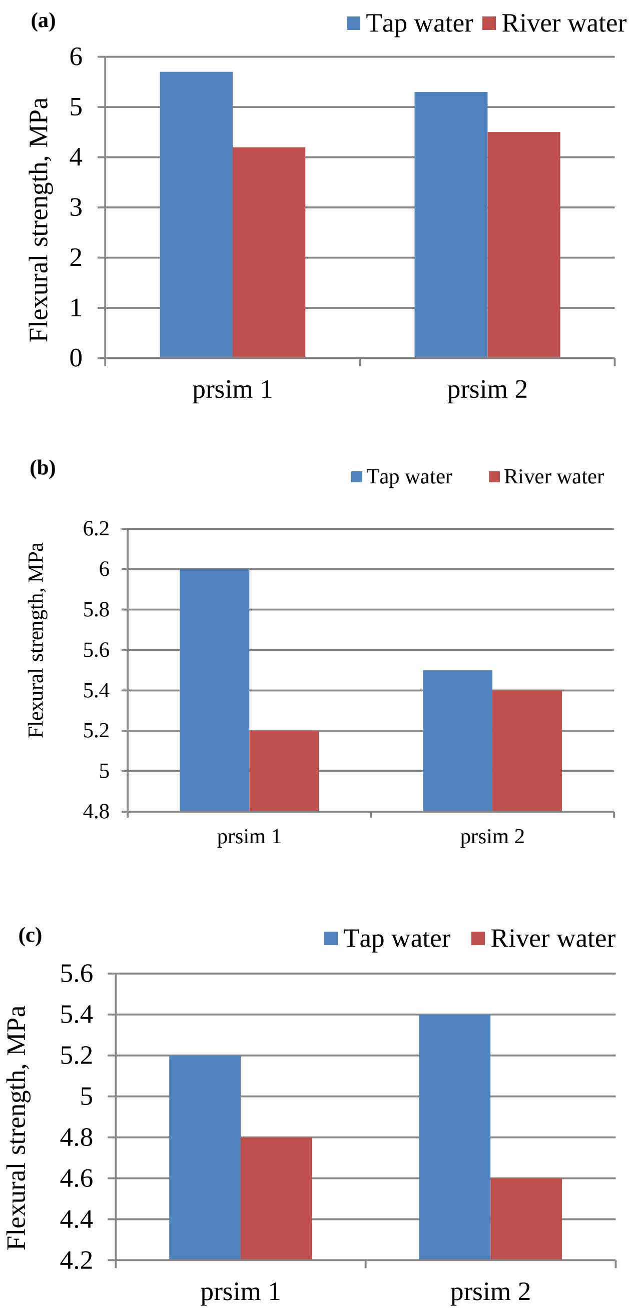


Fig. 7 Flexural strength of control specimens for (a) NC, (b) SCC, and (c) FAC.

The compressive, flexural, and splitting tensile strengths of control specimens were increased by adding silica fume and fly ash to the concrete mixture. For example, the compressive strength of NC did not exceed 30.5 MPa, whereas it reached 60.4 MPa and 44.8 MPa in SCC and FAC, respectively, as shown in Figure 5. Additionally, it was noted that the compressive strength of the concrete samples cured by tap water was higher than that of the other specimens cured in river water by 3%, 5%, and 4.5% for NC, SCC, and FAC, respectively. The results of the higher percentages of compressive strength of the samples cured in tap water are probably attributed to the lower levels of sulfate and magnesium content present in tap water than in the river water, which may weaken the strength of concrete [28, 29]. Moreover, the results indicated that the average splitting tensile strength of the samples cured in tap water was higher than that of the samples cured in river water by 19%, 9.5%, and 17% for NC, SCC, and FAC, respectively. This is likely related to the higher presence of chloride content in river water, which leads to the corrosion of concrete structures and consequently reduces the structural integrity of steel reinforcement to resist the tensile strength [30].

Furthermore, compared to using river water, flexural strength of concrete prisms tests indicated that using tap water for concrete curing increased by 25%, 6%, and 17% for NC, SCC, and FAC, respectively. The higher values of flexural strength are also due to the lower concentrations of sulfate and chloride content in tap water [31]. Previous studies [16, 18] reported that using river water to cure the sample of the concrete elevated its compressive strength from 15% to 29% for 28 days, compared with tap water. However, the results of this study showed a different trend in the properties of the concrete samples. This discrepancy may be related to the different quality of the river water samples used in this study, which have high levels of sulfate, chloride, and organic materials.

3.4. Slabs Tests

3.4.1. Drop Ball Impact

Generally, concrete is a fragile material with high stiffness under compression, which makes it widely used in different applications of construction works, including shock absorbance, railway buffers, bridges, and foundation pads of machinery, and other related applications [32]. The drop ball impact test is an important test that is used to measure the ability of the concrete to absorb energy and evaluate ductility and brittleness by calculating the number of strokes that concrete can withstand before failure. In the experimental test, the number of strokes that cause failure was calculated for each type of concrete slab. Figure 8 shows the number of strokes for all slab specimens. The percentage of increment in the number of strokes of samples cured with tap water to reach failure was approximately 2.5% for all types of concrete slabs. This is probably attributed to the increase in the concentration of sulfate, chloride, and other chemical materials in the river water. High levels of salts and chemicals in river water weaken the overall structure of the concrete, including accelerating rebar corrosion in concrete structures and reducing the durability and strength of concrete [32]. Furthermore, the results displayed that the number of strokes to cause the failure of the samples of SCC and FAC was higher than that required for NC. Adding silica fume and fly ash to the concrete mixture is most likely to enhance its compressive strength and durability, and hence increase the number of strokes [33].

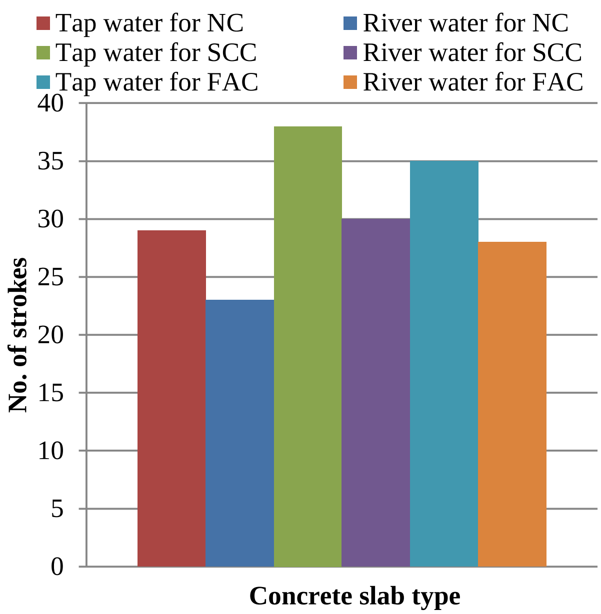


Fig. 8 Number of strokes for each type of concrete slab

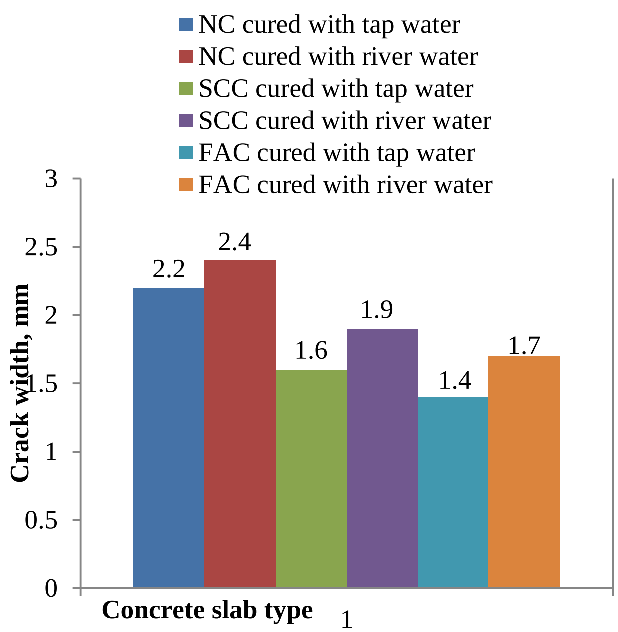
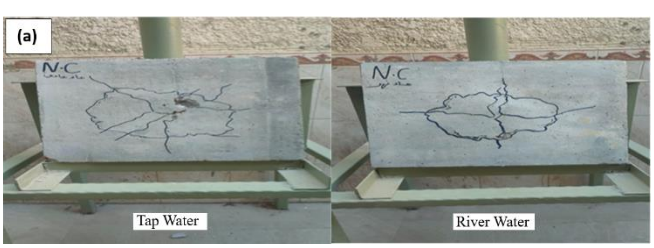


Fig. 9 Crack width of each type of concrete slab



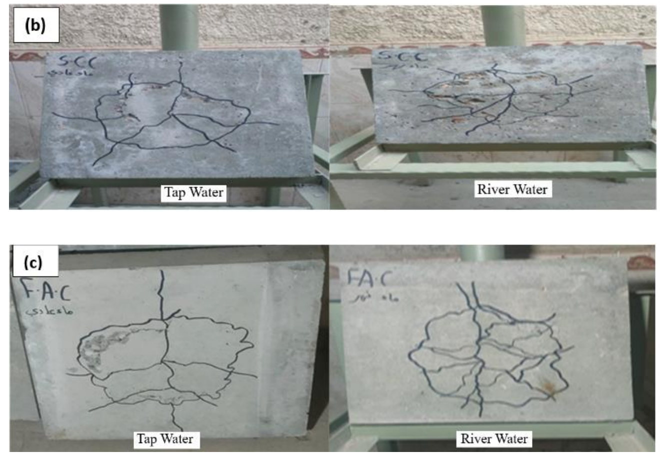


Fig. 10 Modes of failure of (a) NC, (b) SCC, and (c) FAC.

3.5. Crack Patterns and Modes of Failure

The crack width and modes of failure are presented in Figure 9. All the concrete slabs with different mix proportions and curing types showed a punching failure type, as shown in Figure 10. The results exhibited almost identical crack patterns, and the crack widths of the samples cured with tap and river water were very close to each other. However, using river water instead of tap water increased the crack width by 9%, 18%, and 21% for NC, SCC, and FAC, respectively. These increments are most likely due to the impurities present in the river water, which weaken the bonds among the concrete components and, as a result, adversely affect the resistance of the slabs to the imposed load. In addition, the results showed that crack widths of SCC and FAC were smaller than those of NC, and they did not exceed 2 mm. The smaller crack widths observed are probably due to the influence of adding silica fume and fly ash to the mixture, which fills the voids existing in the concrete and thus enhances the resistance to the imposed loads [33].

Overall, the results demonstrated that adding silica fume and fly ash to the concrete mixture significantly enhanced its properties, such as reducing crack width and increasing strength and number of strokes until failure occurred. In addition, using river water instead of tap water to cure the concrete slabs noticeably increased the crack widths, caused more branching cracks, and resulted in a quicker failure of the concrete slabs. The development of branching cracks in concrete is most likely a consequence of impurities in river water, such as sulfate and magnesium ions, organic matter, and clay. These impurities lead to the expansion and erosion of concrete and, consequently, reduce its strength and durability [34].

4. Conclusion

The study investigated the influence of concrete curing on the behavior and strength of three types of concrete slabs, NC, SCC, and FAC, as well as the influence of dynamic loads on the concrete slabs. Two different types of water (tap and river) were used to cure the specimens. The results elucidated that SCC achieved higher compression strength by about 50% and 26%, compared to NC and FAC, respectively. The higher compression strength of SCC is related to the addition of formed steel fibers, silica fume, and Glenium 51, which enhance the cohesion of the concrete components to each other and increase its strength and durability. Additionally, the compressive, tensile, and flexural strengths of the control specimen cured with tap water displayed higher values than those of river water. This is probably attributed to the high levels of certain constituents in river water, which negatively affect the properties of reinforced concrete. These impurities included high levels of chlorides and sulfates. Moreover, the physical properties of the concrete slabs were enhanced by adding silica fume and fly ash. This was indicated by the higher number of strokes to cause the failure of the samples of SCC and FAC compared to those required for NC. Furthermore, all the concrete slabs with different mix proportions and curing types showed almost the same crack patterns with punching failure. However, water quality analysis for both river water and tap water was conducted to determine the levels of the contaminated substances that may negatively impact the concrete properties. In addition, water quality analysis implies the reasons behind the differences in the results of using the two water sources, by individually comparing the levels of the water parameters. On the other hand, using river water rather than tap water in concrete works contributes to environmental sustainability by reducing the impact of chemical use and waste generation of the water treatment processes. [35]. All in all, it is possible to use river water for concrete curing, especially in areas with a shortage of treated water or where the river water source is very close to the construction sites.

Authors' Contribution Statement

LM and SM conceived and designed the research. LM conducted experiments. DE contributed new reagents or analytical tools. LM and DE analyzed data. SM and DE wrote the manuscript. All authors read and approved the manuscript.

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