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Impact of Different Curing Techniques in Evaluating the Strength of the Roller Compacted Concrete Containing Waste Materials

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ABSTRACT

The main objective of this laboratory study was to produce environmentally friendly, sustainable roller-compacted concrete (SRCC) that meets the required strength by utilizing waste building materials such as waste thermostone block as a partial volume replacement of fine aggregate by two percentages (15% and 30%) and filler by 50%. Along with standard curing, three different curing regimes were tested: spray-water, liquid-membrane compound (Sika Antisol-WB), and damp-burlap. Regarding the curing methods, the liquid-membrane compound achieved the best results compared to standard-curing, followed by damp-burlap. On the other hand, spray-water resulted in the poorest performance, yielding lower results than standard-curing. The results showed that the SRCC mixture containing waste thermostone block (by 15% substitute of fine aggregate and by 50% substitute of filler) improved the compressive, flexural, and tensile strengths by 1.66%, 1.51%, and 1.68%, respectively, after 28 days of standard-curing compared to the reference-mixture. While the SRCC mixture containing waste thermostone block (by 30% substitute of fine aggregate and by 50% substitute of filler) deteriorated the compressive, flexural, and tensile strengths by 4.97, 4.24, and 3.98%, respectively, after 28 days of standard-curing compared to the reference-mixture.

Keywords: Sustainable roller-compacted concrete, Waste thermostone block, External curing techniques, Internal curing.

1. INTRODUCTION

Roller-compacted concrete (RCC) is a solid, and the concrete should have zero slump. RCC has benefits for the environment and the economy over traditional concrete. Conventional concrete typically contains about 15% cementitious materials, whereas the RCC mixture reduces this to approximately 12%; Due to the rising prevalence of industrial waste, several academics have concentrated on recycling solutions recently **(Al-Ani and Abbas, 2025)**. A concrete pavement with 0% slump that is made of water, aggregates, and cement is called

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roller-compacted concrete (RCC). This mixture is made using regular asphalt paving equipment, and then a vibratory roller is used to compact and flatten it. The RCC may be utilized on warehouse floors, army vehicle terminals, mine-access streets and ports, factory floors of factories, and lots for parking **(ACI 325, 2001)**. In RCC, building waste materials are utilized in part to substitute natural aggregates and cement. This method could reduce the cost of producing concrete while also being environmentally beneficial. Because this sector utilizes a lot of raw resources, wrongly disposes of trash, and produces a lot of greenhouse gases, researchers are trying to improve sustainable roller compacted concrete (SRCC) innovation **(Zimmermann et al., 2005)**. To mitigate the adverse environmental effects of building waste, waste materials can be used in a variety of applications, such as SRCC. This study examines the effects of using thermostone powders on the mechanical properties of RCC. This was accomplished by crushing, grinding, and blending the waste materials before using them as filler in the RCC **(Abbas, 2022)**. Every year, a huge volume of building waste materials is produced by the construction industry. Finding a method to recycle building trash is crucial because these materials are difficult to handle and, as was previously mentioned, they pose numerous environmental harm issues. In this research, building waste materials such as thermostone have been employed in the production of RCC as filler materials, and their suitability in relation to the mechanical properties of RCC has been examined **(Abbas, 2022)**. The main goal of the laboratory research was to create environmentally friendly RCC by reducing the amount of fine aggregate by employing the ACI 327R, 2015, and utilizing disposed waste material. In order to avoid utilizing a sanitary landfill, the ideal method for disposing of the waste materials from buildings that have been demolished, such as thermostone blocks, was to gather them, crush them using a crushing machine, and then grade them by screening them to a fine aggregate. Reference-mixture (RM) and eco-friendly RCC mixtures were created by substituting (10 and 20) % of the content of fine aggregate with waste materials like thermostone **(Shamran and Abbas, 2023)**. By employing varying percentages of recycled demolition waste materials, the study's most advantageous features include preserving tens of thousands of critical elements necessary for environmental safety and lowering garbage removal expenses, which were predicted to increase as a result of increased landfill taxes. Thermostone block as a partial substitute for fine aggregate in the project to achieve the necessary long-term **(Shamran and Abbas, 2023)**.

The goal of this study is to create sustainable, high-strength, and eco-friendly SRCC by using waste materials such as waste thermostone (WT) collected from factories and destroyed constructions instead of fine aggregate by (15% and 30%) and filler by (50%).

2. EXPERIMENTAL PROGRAM

2.1 Materials Properties

2.1.1 Combined Aggregate

The proportions of the combined aggregate were established at 5% filler, 55% coarse aggregate, and 45% fine aggregate in accordance with **(ACI 211.3R, 2002; ACI 327R, 2015)** requirements. The gradation curve of the aggregate used in the mixture for this research is illustrated in **Fig. 1** and **Table 1**, and the specification limits were established in accordance with **(ACI 327R, 2015)**.

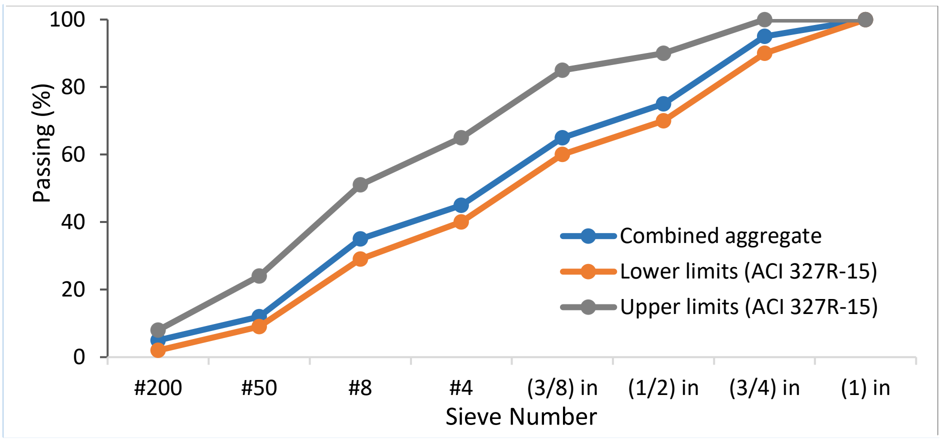

Figure 1. Combined aggregate gradation

Table 1. Gradation of the combined aggregate

Sieve number	Passing (%)	(ACI 327R, 2015) limits
1 (in)	100	100
¾ (in)	95	90-100
½ (in)	75	70-90
⅜ (in)	65	60-85
#4	45	40-65
#8	35	29-51
#16	28	20-40
#30	23	14-31
#50	12	9-24
#100	10	5-19
#200	5	2-8

2.1.1.1 Coarse Aggregate

The coarse aggregate consisted of crushed stone with a maximum particle size of (3/4) inch (19.5mm), conforming to the grading requirements outlined in **(ASTM C33, 2016)**. The selected sizes for the coarse aggregate included [sieve No.4, sieve (3/8) inch, sieve (1/2) inch, and sieve (3/4) inch]. The particle size distribution was calculated through sieve analysis. The coarse aggregate properties listed in **Table 2** and the sieve analysis in accordance with **(ASTM C136M, 2019)**.

Table 2. Properties of coarse aggregate

Criteria	Result	Limit (IQS No.45, 1984)
Specific-gravity	2.61	-
Absorption	0.62%	-
Sulfur trioxide SO_3	0.069%	≤ 0.1
Fineness modulus	6.9	

2.1.1.2 Fine Aggregate

The fine aggregate used in the mix conformed to the grading limits of (Zone 2), as specified by **(ASTM C33, 2016)**. The particle size distribution was verified through sieve analysis. The fine aggregate properties listed in **Table 3** and the sieve analysis in accordance with **(ASTM C136M, 2019)**.

Table 3. Characteristics of fine aggregate

Criteria	Result	Limit (IQS No.45, 1984)
Specific-gravity	2.58	-
Absorption	1.60%	-
Sulfur trioxide SO_3	0.343%	≤0.5
Dry density (Rodded)	1799 kg/m^3	-
Fineness modulus	2.8	

2.1.1.3 Filler

Limestone filler (LF) was selected from crushed limestone aggregate with particle sizes passing sieve No.200 (0.075mm). The limestone filler (LM) properties are listed in **Table 4.** As shown below, **Fig. 2** illustrates the aggregate gradation in the mixture.

Table 4. Properties of limestone filler (LF)

Criteria	Result	Limit (IQS No.45, 1984)
Specific-gravity	2.84	-
Absorption	2%	-
Dry density (Rodded)	1213 kg/m^3	-

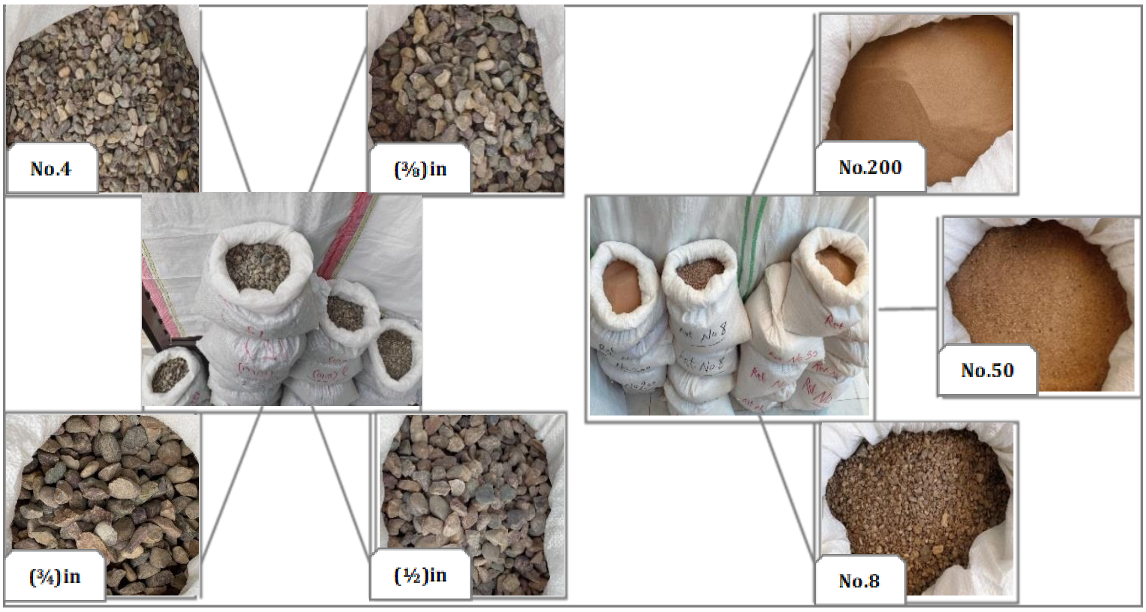

Figure 2. Different sizes of separated aggregate

2.1.2 Cement

Ordinary-Portland Cement (O-PC) (Type 1) (42.5R), produced by Al Mass Company for Cement Industries and conforming to **(ASTM C150, 2018)**, was used in this study. The physical properties and chemical composition of the cement are presented in **Table 5.**

Table 5. Physical and chemical requirements of ordinary Portland Cement (O-PC)

Physical requirement			
Test		**Results**	**(IQS No.5, 2019)**
Setting Time	Initial	90 (hr: min)	00:45 Min.
	Final	4.42 (hr: min)	10:00 Max.
Compressive Strength	2-days	21.75 MPa	20 Min.
	28-days	46.63 MPa	42.5 Min.
Fineness, specific-surface by air permeability apparatus		349.8 m^2/kg	280 Min.
Chemical requirements			
Properties	**Chemical compounds**	**Results**	**(IQS No.5-19)**
Silicon oxide	SiO2	20.64%	-
Aluminium oxide	AL2O3	5.08%	-
Ferric oxide	Fe2O3	4.16%	-
Calcium oxide	CaO	60.35%	-
Magnesium oxide	MgO	3.86%	5.0 Max.
Sulfate-trioxide	SO3	2.67%	2.8 Max. If C3A > 3.5 %
Insoluble-residue	I.R.	0.86%	1.5 Max.
Loss on Ignition	L.O.I.	3.21%	4.0 Max.
Main Compound by Bogue's Equation			
Di-calcium silicate	C2S	27.83	-
Tri-calcium silicate	C3S	41.07	-
Tri-calcium aluminate	C3A	6.43	-
Tetra-calcium Alumina ferrite	C4AF	12.64	-

2.1.3 Water

The mixtures were prepared using the municipal water supply from Iraq, which complies with the requirements of **(IQS No.1703, 2018)**.

2.1.4 Waste Materials

Waste thermostone blocks (WT) were taken from the factories for use in the production of sustainable roller-compacted concrete (SRCC) and for sand disposal. The first mixture [(15%) of the fine aggregate + (50%) of the limestone filler (LF)] was replaced with a waste thermostone block (WT15). Also, the second mixture [(30%) of the fine aggregate + (50%) of the limestone filler (LF)] was replaced with waste thermostone block (WT30). The waste thermostone blocks were first broken using a hammer, crushed with a crusher machine, and then sieved to prepare waste sand. A storm machine can prepare the filler. **Fig. 3** illustrates the crushing and grinding process of the waste materials using specialized machinery. This procedure was created at the (Building Research Center) located in Baghdad, Iraq. **Table 6** presents the results of the tests performed on waste thermostone block (WT), including water absorption and specific gravity determined in accordance with **(ASTM C128, 2017)**, as well as bulk density measured according to **(ASTM C29, 2015)**.

Table 6. Properties of thermostone

Property	Results
Dry density (Rodded)	584 kg/m^3
Specific-gravity	0.87
Absorption	45%
SO_3	0.963%

Figure 3. The steps of preparation waste thermostone block (WT)

2.2 Curing Techniques

Two types of curing methods were adopted in this study: external curing and internal curing.

2.2.1 External curing

In this study, a combination of conventional [standard-curing (SC)] and advanced curing methods was selected to evaluate their influence on the durability of SRCC. This approach aimed to simulate realistic site conditions, providing a comprehensive understanding of how different curing techniques impact concrete performance. As shown below, appear types of curing techniques appear:

- Standard-Curing (SC):

Concrete specimens were treated by submersion in a water tank, where the water temperature was regulated and maintained at (23±2) °C.

- Spray-water (SWC):

Continuous surface wetting was achieved by spraying water onto the concrete using water sprinklers.

- Liquid-membrane compound (LMC):

In accordance with **(ASTM C309, 2019)**, a Liquid-membrane compound (Sika antisol-WB) (LMC) was utilized on the concrete surfaces to reduce moisture evaporation and promote effective curing.

- Damp-burlap (DBC):

Curing was carried out utilizing damp white burlap coated with a polyethylene sheet in accordance with **(ASTM C171, 2016).** The sheet had a minimum weight of (305 gm/m^2) and was bonded to a white opaque polyethylene film with a minimum thickness of (0.10mm) on one side.

2.2.2 Internal curing

Internal curing is regarded as a very promising method that adds more moisture to the concrete matrix, boosting cement hydration and concrete performance in general. The extent of cement hydration and the degree to which the hydration products occupy the pore spaces between cement particles are critical factors influencing the strength and durability development of concrete **(Rasheed et al., 2021)**. For effective internal curing, the curing agent must possess a high water absorption capacity and the ability to efficiently release the absorbed water under pressure, ensuring a more complete and effective hydration process **(Golias et al., 2012)**.

2.3 Casting and Mixture Content

Since sustainable roller-compacted concrete (SRCC) is relatively dry, achieving the highest possible density requires strict compatibility in accordance with **(ACI 327R, 2015)** guidelines. Among the factors influencing compatibility, the moisture content of the mixture plays the most critical role. To establish the relationship between moisture content and dry density for SRCC, the alternate proctor compaction method specified in **(ASTM D1557, 2012)** is commonly used. This method determines the optimum moisture content in (%) and maximum dry density in (kg/m^3). A five-point modified proctor curve is developed by testing moisture contents ranging (4.5 to 8.5) % in (1) % increments. The procedures for conducting the alternate proctor test are illustrated in **Fig. 4**.

The material proportions for one cubic meter (1 m^3) of sustainable roller-compacted concrete (SRCC) are presented in **Table 7**. The (water-to-cement) ratio of the mixture was selected based on the optimum moisture content determined from the proctor test. Given that SRCC exhibits considerably drier consistency compared to conventional concrete, a specialized compaction procedure is required during placement. After the preparation and mixing of the elements, cylindrical and prismatic specimens were compacted using a vibratory hammer and a compression plate, as illustrated in **Fig. 5**.

The vibratory hammer (VH) and tamping plate (CP) used in this process were designed in accordance with **(ASTM C1435, 2014)**. **Fig. 6** details the specifications of the VH and TP utilized for the cylindrical and prismatic molds. Finally, the prepared SRCC specimens were subjected to curing.

Table 7. Mixing Quantity for SRCC in 1m^3

Materials	**Weight**
Cement (kg)	280.2
Water (kg)	106.7
Saturated surface dry (SSD) 85% of fine aggregate (kg)	710.0
(SSD) Replacement of fine aggregate by 15% of thermostone sand	58.04
Saturated surface dry (SSD) 50% of limestone filler (LF) (kg)	52.41
Saturated surface dry (SSD) replaced by (LF) with 50% of thermostone filler	74.50
Materials	**Weight**
Cement (kg)	281.5
Water (kg)	94.09
Saturated surface dry (SSD) 70% of fine aggregate (kg)	587.4
(SSD) Replacement of fine aggregate by 30% of thermostone sand	116.6
Saturated surface dry (SSD) 50% of limestone filler (LF) (kg)	52.65
Saturated surface dry (SSD) replaced by (LF) with 50% of thermostone filler	74.85

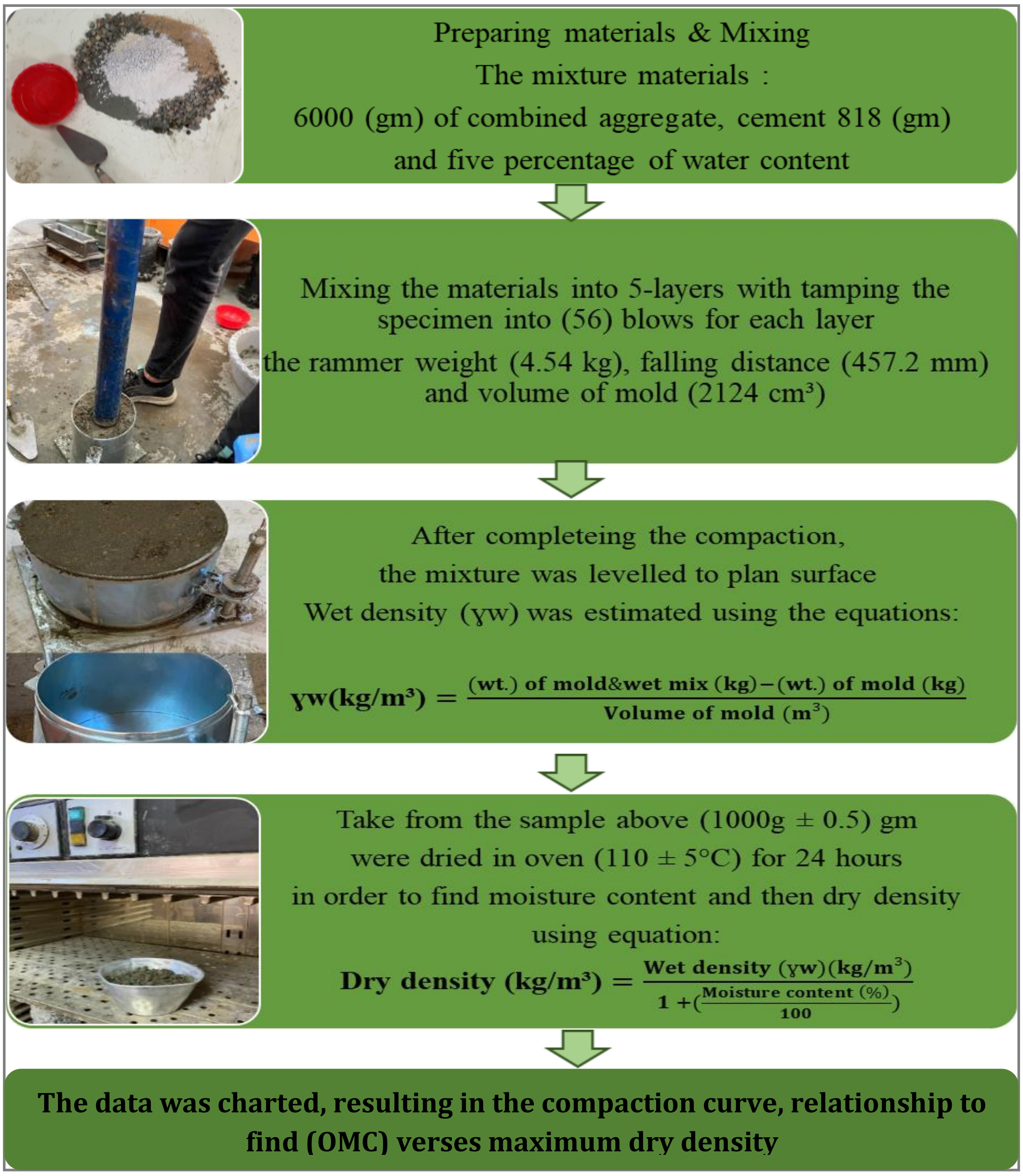

Figure 4. Modified proctor test steps according to (**ASTM D1557, 2012)**

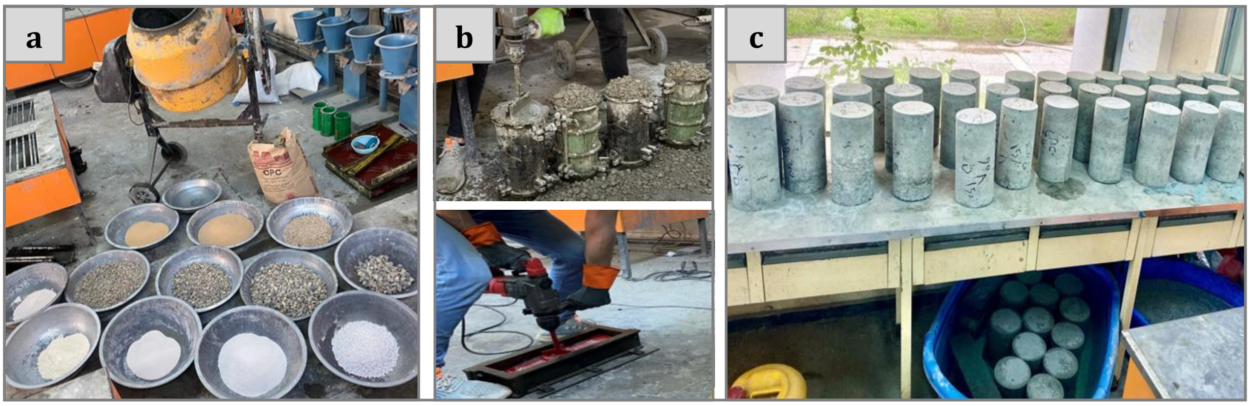

Figure 5. (a) Preparing material and mixing, (b) The compaction for cylinder and prism, (c) The samples after casting

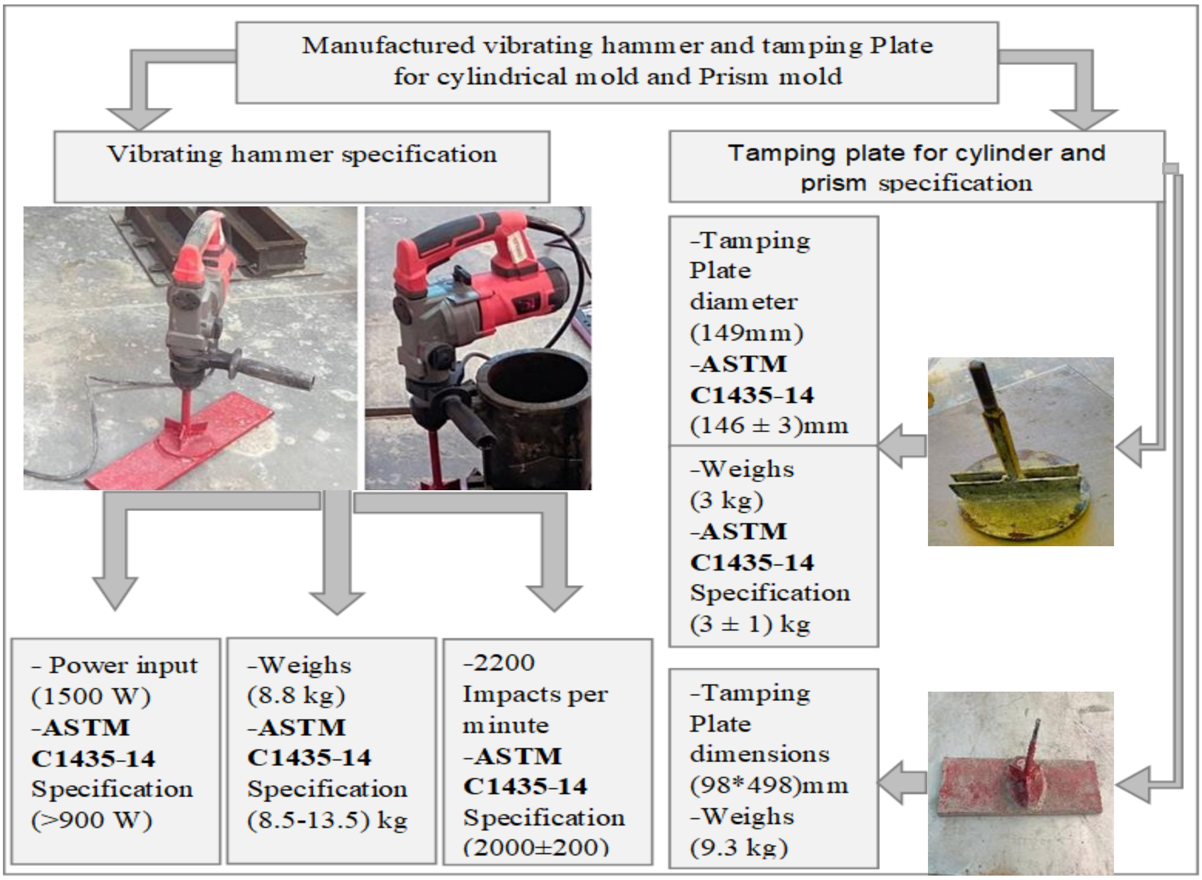

Figure 6. Technical specifications of the produced vibrating hammer (VH) and tamping plate (TP) for the prism mold and cylindrical

2.4 Application of External Curing Techniques

Four different curing methods were applied to roller-compacted concrete specimens, both cylindrical and prismatic, to evaluate their performance in the flexural strength test, compressive strength test, and splitting tensile strength test:

- Standard-Curing (SC):

After 24 hours of casting, the specimens were removed from the molds and immersed in a water tank for periods of 7, 28, and 90 days to monitor the evolution of their mechanical properties, as shown in **Fig. 7**.

Figure 7. Standard-curing (SC)

- Spray-water (SWC):

After 24 hours of casting, the specimens were subjected to water spraying for 3 days, with two spray applications per day (separated by a 6-hour interval). Following this, the specimens were left in the air for periods of 7, 28, and 90 days to monitor the development of their mechanical properties, as shown in **Fig. 8**.

Figure 8. Spray-water (SWC)

- Liquid-membrane compound (LMC):

After 2 hours of casting, the specimens were treated by applying the liquid membrane only to the top surface. After 24 hours, the molds were removed, and the specimens were sprayed with the liquid membrane on all sides. Following this, the specimens were left in the air for periods of 90, 28, and 7 days to observe the development of their mechanical properties, as shown in **Fig. 9**.

Figure 9. Liquid-membrane compound (LMC): (a) Sika Antisol-WB, (b) Sprayed on the top of the surface, (c) After being taken out of the mold

- Damp-burlap (DBC):

After casting, damp burlap was placed over the specimens, followed by a layer of polyethylene sheet. After 24 hours, the molds were removed, and the specimens were wrapped in damp burlap and polyethylene sheet for an additional 2 days. Subsequently, the specimens were left in the air for periods of 7, 28, and 90 days to monitor the development of their mechanical properties, as shown in **Fig. 10**.

Figure 10. Damp-burlap (DBC): (a) Burlap coated with polyethylene sheet, (b) Immediately after casing

2.5 Test Methods

2.5.1 Slump Test

According to the standard outlined in **(ASTM C143/C143M-03, 2003)**, the slump of the Abrams cone is measured to ascertain the consistency of the mortar. Three layers of fresh mortar are poured, each of which is equal to one-third of the height of a steel mold in the shape of a truncated cone. Using a tamping rod, 25 strokes are used to compact each layer of fresh mortar. The strokes are spaced out in a spiral pattern, going from the edge of the mold to its center. The mold is taken out once the last layer has been compacted, and the slump is measured without delay. As the slump increases, the consistency of the sample decreases, and its workability increases. **Fig. 11** illustrates the measurement and compaction phases of the test.

Figure 11. Slump Test

2.5.2 Compressive Strength Test

The average compressive strength test was calculated adopting with **(ASTM C39/C39M, 2015)**. The compressive strength test was carried out on cylindrical samples with a diameter of 15 cm and a height of 30 cm, utilizing a compression testing machine with a capacity of 3000 kN. The loading rate specified in **(ASTM C39/C39M, 2015)** is (0.25 ± 0.05) N/mm^2/second. The compressive strength test of two samples was determined following the guidelines of **(ACI 327R, 2015)**. The average compressive strength test was then calculated based on the results. As illustrated in **Fig. 12**, Eq. (1) was utilized to compute the compressive strength testing.

$$\text{Compressive strength (MPa)} = \frac{\mathbf{P}}{\mathbf{A}} \tag{1}$$

Where:
P: maximum applied load indicated by the testing machine (N)
A: area exposed to load (mm^2)

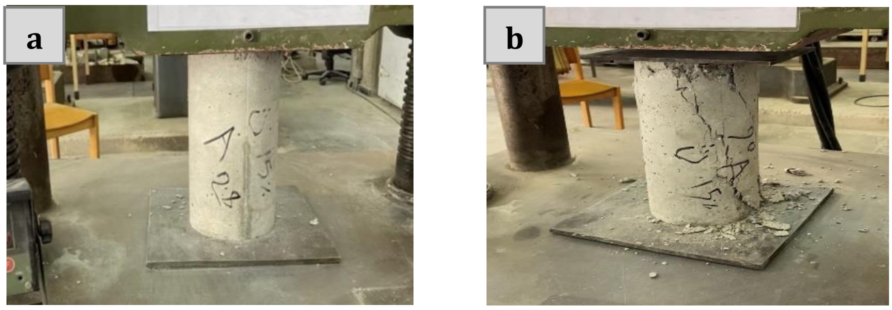

Figure 12. (a) Compressive test machine, (b) SRCC sample after failure

2.5.3 Splitting Tensile Strength Test

The splitting tensile strength of cylindrical specimens (150 mm diameter, 300 mm height) was determined in accordance with **(ASTM C496/C496M, 2011)**. A (3000 kN) compression machine was used to apply the load at a rate of 1.2 MPa/min within the 0.7-1.4 MPa/min range specified by the standard. As shown in **Fig. 13**, the tensile strength for each sample was calculated using Eq. (2), and the test results were reported as the average splitting tensile strength.

$$\text{Splitting tensile strength test} = \frac{\mathbf{2*P}}{\boldsymbol{\pi}\mathbf{*D*L}} \tag{2}$$

Where:
L: length (mm)
D: diameter (mm)

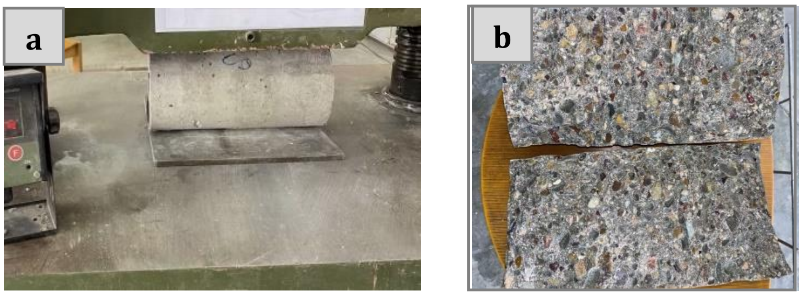

Figure 13. (a) Splitting tensile test machine, (b) SRCC sample after failure

2.5.4 Flexural Strength Test

The flexural strength of the specimens was measured using center-point loading in accordance with **(ASTM C293/C293M, 2016)**. The applied loading rate was 1.2 MPa/min, which lies within the 0.9-1.2 MPa/min range specified by the standard. As shown in **Fig. 14**, the flexural strength values were then calculated using Eq. (3).

$$\text{Flexurastrength (MPa)} = \frac{\mathbf{3*L*P}}{\mathbf{2*b*d^2}} \tag{3}$$

Where:
d: average thickness of a sample (mm)
b: average width of a sample (mm)
L: span length of the sample (distance between supports) (mm)

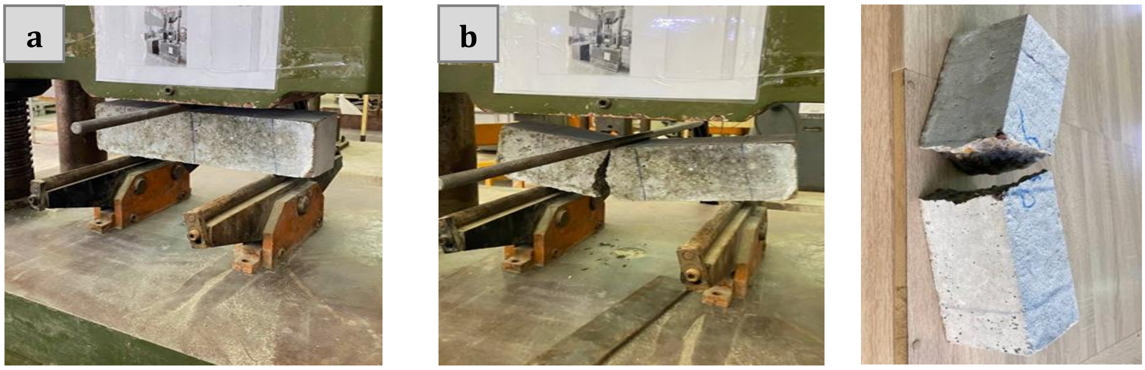

Figure 14. (a) Flexural test machine and static scheme, (b) SRCC sample after failure

3. RESULTS AND DISCUSSION

3.1 Compressive Strength Test

The results of the laboratory work displayed that the compressive strength test increased when using [15% of thermostone sand waste as replacement of sand plus 50% as filler (WT15)] equal to (1.66) % at 28 days for standard-curing (SC) when compared to reference-mixture (RM), as shown in **Fig. 15**. The improvement may be attributed to the internal curing which can be more significant in zero in slump concrete. Although the ability absorption of thermostone (45%), the internal curing effects are less significant as present in the percentage improvement compressive strength test results. These behaviours may be due to the thermoset texture and shape prepared sand, so the bond strength between cement paste and fine aggregate interfacial transition-zone (IT-Z) is less noticeable **(Gawad and Fawzi, 2021)**, considering the variance in concrete mix. When the thermostone sand waste content increased to 30% plus 50% as filler (WT30), compressive strength test at 28 days deterioration equal to (4.97) % for standard-curing (SC) when compared to reference-mixture (RM). Due to the interfacial transition-zone (IT-Z) becoming somewhat weaker.

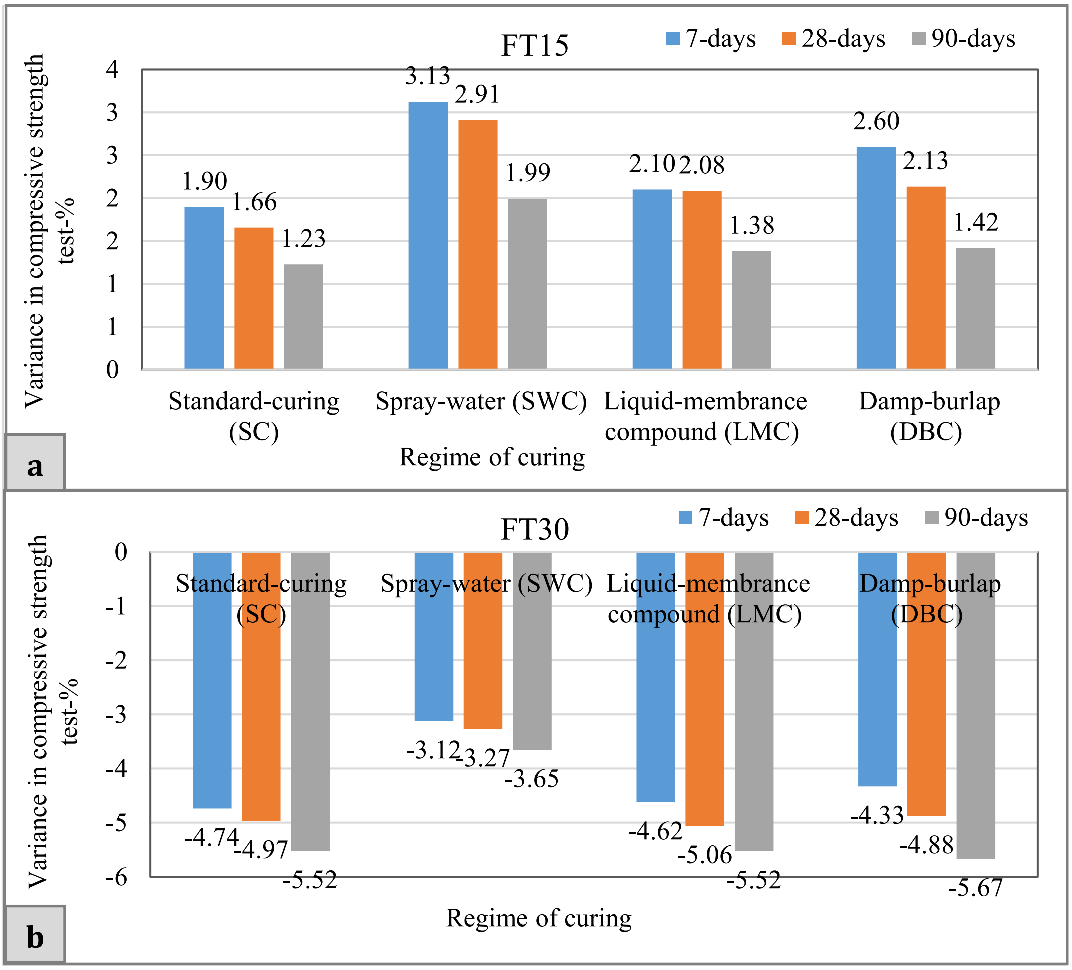

Figure 15. Compressive strength test percentages: a) Increase of WT15 compared with reference-mixture (RM), b) Decrease of WT30 compared with reference-mixture (RM)

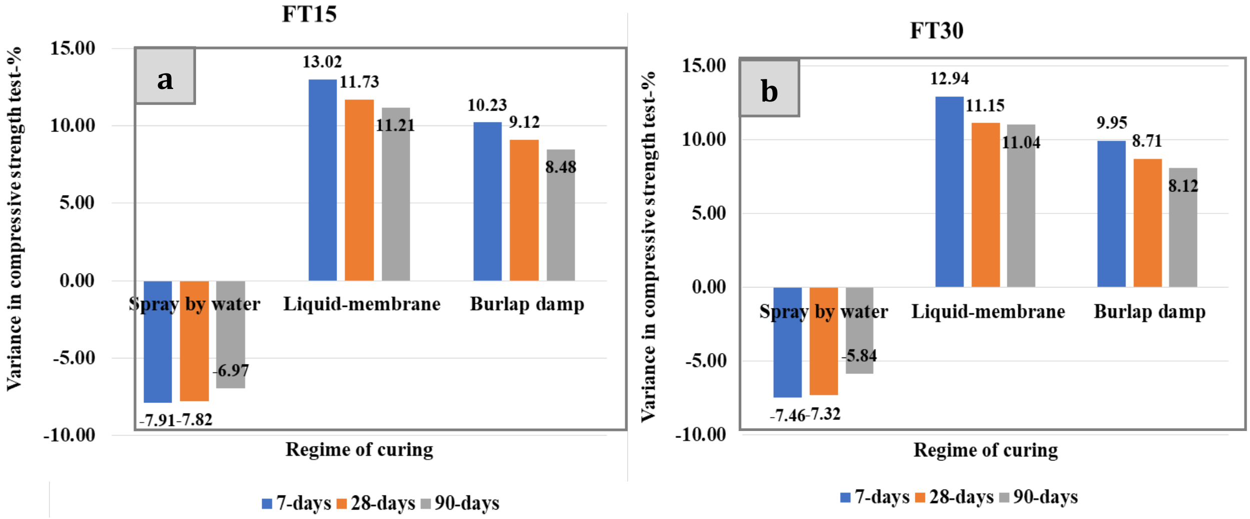

Figure 16. Percentage variance in compressive strength test for different curing compared with standard-curing for: a) FT15, and b) FT30

This may be attributed to the thermostone sand waste texture and the ability to combine with cement paste and aggregates. These conforming results of **(Gawad and Fawzi, 2021)** consider the difference in concrete mix type. As shown in **Fig. 16**, the effects of curing for WT15 and WT30 compared to standard-curing (SC) can be by improvement or retardation. The reduction of spray-water (SWC) results equal to 7.82 % for WT15 and 7.32 % for WT30 at 28 days compared with standard-curing (SC) and this can be explained by the loss of water by evaporation as also presented by **(Hassoon and Abbas, 2024)** and the results also close to finding by **(Luti, 2024)**, take to consideration the difference in concrete mixture type. The decrease in compressive strength test percentage should be of concern in the field, and take care when the construction is done in our local hot weather in summer.

The improvement in compressive strength test percentage in both methods by [liquid-membrane compound (LMC) and damp-burlap (DBC)] is equal to (11.73 and 9.12) % respectively for WT15 and (11.15 and 8.71) % for WT30 at 28 days, compared to standard-curing (SC).

That can be explained by keeping the ratio of mixing water and the reaction of the best chemical cement ingredients **(Abd AlMajeed and Abbas, 2024; Salih et al., 2014; Vandenbossche, 1999)**. Standard-curing (SC) is lower than damp-burlap (DBC) due to the leaching of $Ca(OH)_2$ when the curing water is not saturated. The higher enhancement of liquid-membrane compound (LMC) than damp-burlap (DBC) may be due to the high ability of liquid-membrane compound (LMC) to maintain moisture and lessen the loss of evaporation.

3.2 Flexural and Tensile Strength Tests

The results of the laboratory work showed that the flexural and splitting tensile strength tests at 28 days increased when using [15% of thermostone sand waste as replacement of sand plus 50% as filler (WT15)], equal to (1.51, 1.68) %, respectively for standard-curing (SC) when compared to reference-mixture (RM), as shown in **Figs. 17** and **19**. The improvement may be attributed to the internal curing, which can be more significant in zero-slump concrete. Although the ability absorption of thermostone (45%), the internal curing

effects are less significant as present in percentage improvement compressive strength test results. These behaviors may be due to the thermostone texture and shape prepared sand, so the bond strength between cement paste and fine aggregate interfacial transition-zone (IT-Z) is less noticeable **(Gawad and Fawzi, 2021)**, considering the variance in concrete mix. When the thermostone sand waste content increased to 30% plus 50% as filler (WT30), flexural and tensile strength tests at 28 days of deterioration equal to (4.24, 3.98) %, respectively, for standard-curing (SC), when compared to reference-mixture (RM). Due to the interfacial transition-zone (IT-Z) becoming somewhat weaker.
This may be attributed to the thermostone sand waste texture and the ability to combine with cement paste and aggregates. These conforming results of **(Gawad and Fawzi, 2021)** consider the difference in concrete mix type.

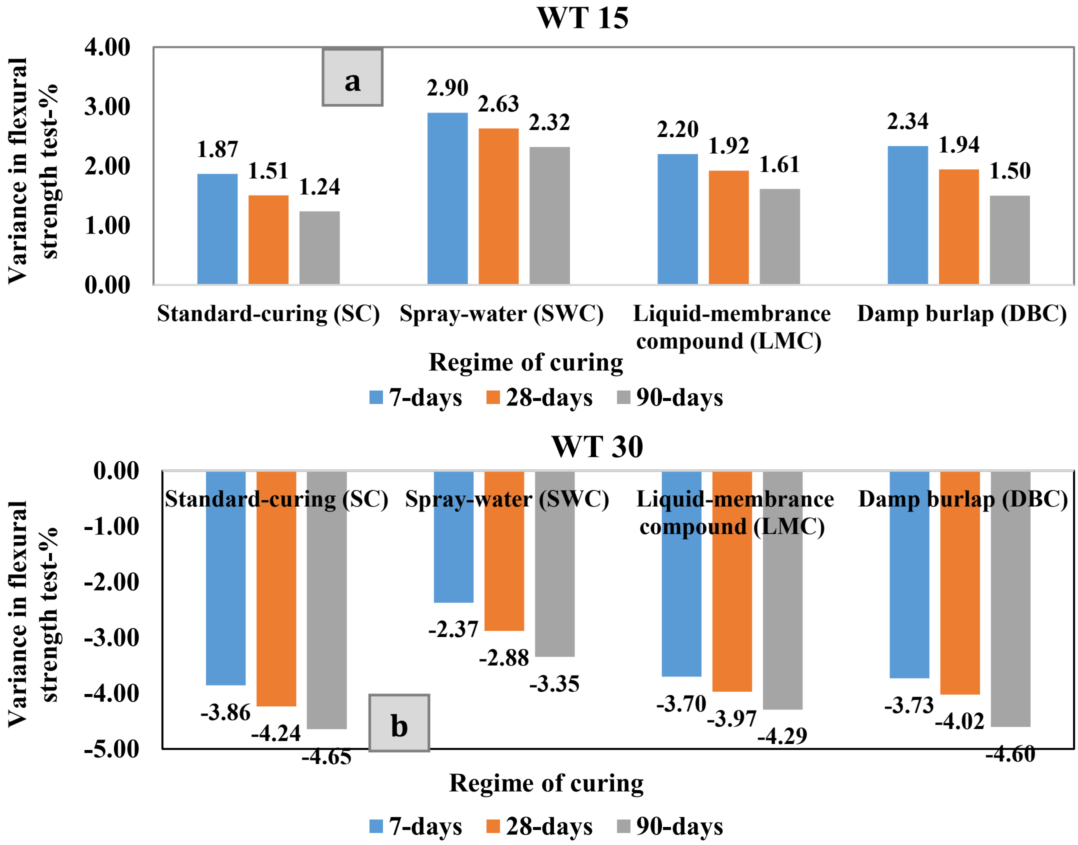

Figure 17. Flexural strength test percentages: a) Increase of WT15 compared with reference-mixture (RM), b) Decrease of WT30 compared with reference-mixture (RM)

As shown in **Figs. 18** and **20,** the effects of curing for WT15 and WT30 compared to standard-curing (SC) can be by improvement or retardation. The reduction in flexural and splitting tensile strength tests of spray-water (SWC) results equal to (6.13 and 5.70) %, respectively for WT15 and (5.85 and 4.98) %, respectively for WT30 at 28 days compared with standard-curing (SC) and this can be explained by the loss of water by evaporation as also presented by **(Hassoon and Abbas, 2024)** and the results also close to finding by **(Luti, 2024)**, take to consideration the difference in concrete mixture type. The decrease in compressive strength test percentage should be of concern in the field, and take care if the construction is done in our local hot weather in summer.

The improvement in flexural and tensile strength tests percentage in both methods by [liquid-membrane (LMC) and damp-burlap (DBC)] equal to (9.97 and 7.23) % and (9.31 and 5.50) %, respectively for WT15 and [(9.83 and 7.01) % and (9.37 and 5.12) %], respectively for WT30 at 28 days compared to standard-curing (SC). That can be explained by to retention of mixing water and good chemical cement ingredients' reaction **(Abd Almajeed and Abbas, 2024; Salih et al., 2014; Vandenbossche, 1999)**.

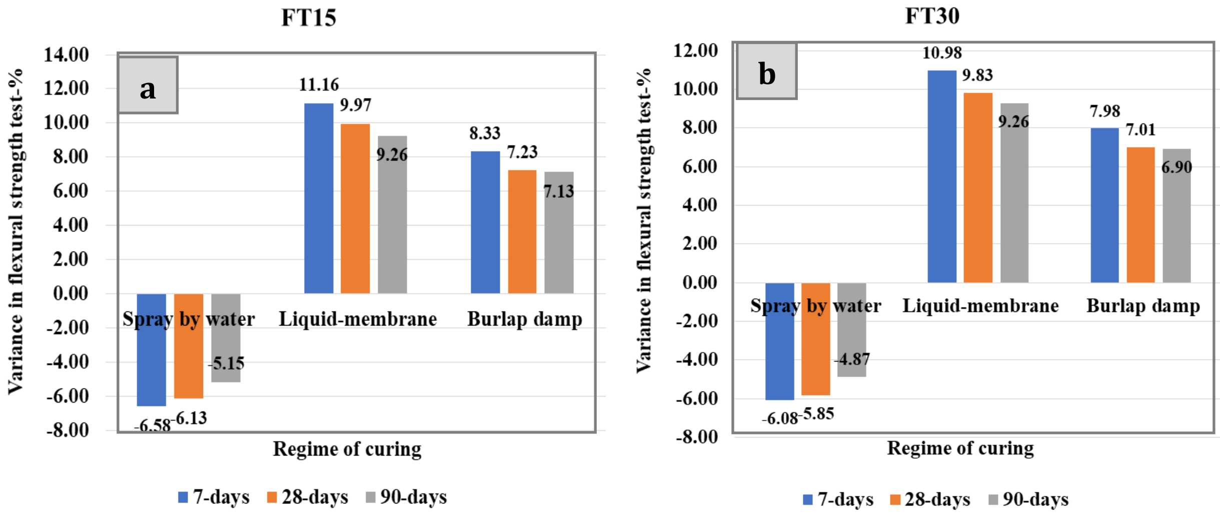

Figure 18. Percentage variance in flexural strength test for different curing compared with standard-curing for: a) FT15, and b) FT30

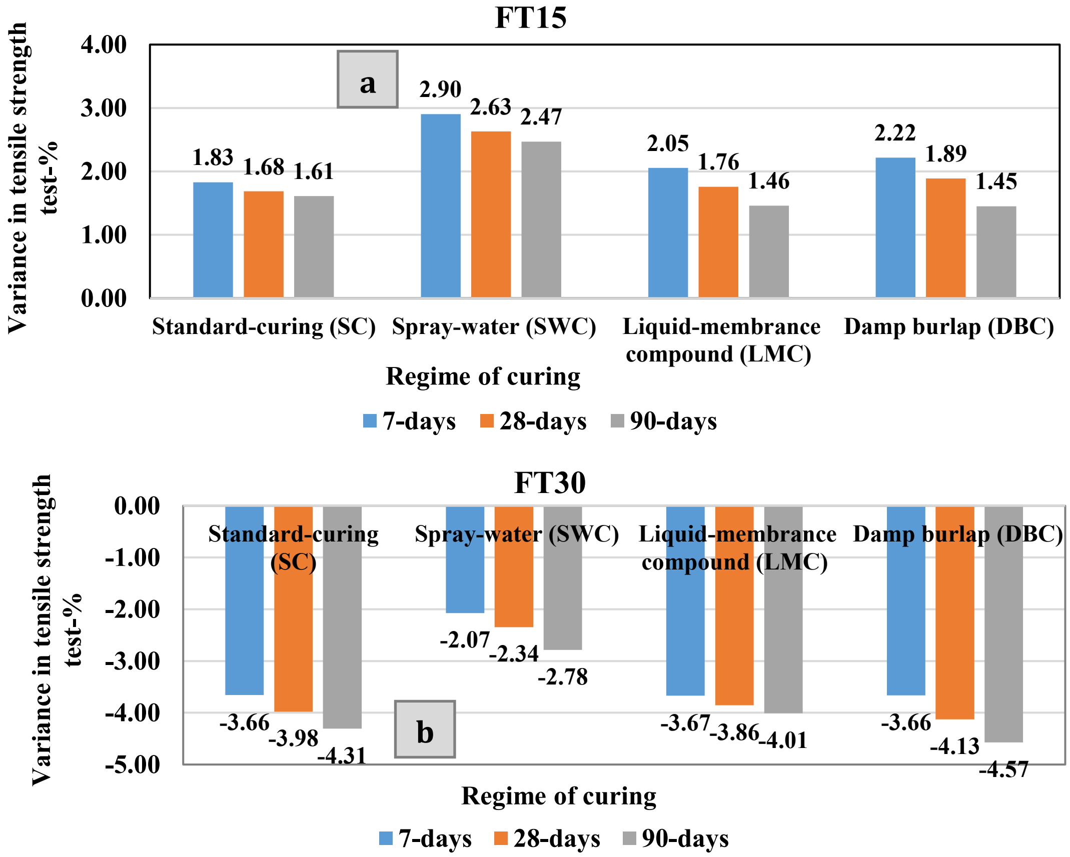

Figure 19. Tensile strength test percentages: a) Increase of WT15 compared with reference-mixture (RM), b) Decrease of WT30 compared with reference-mixture (RM)

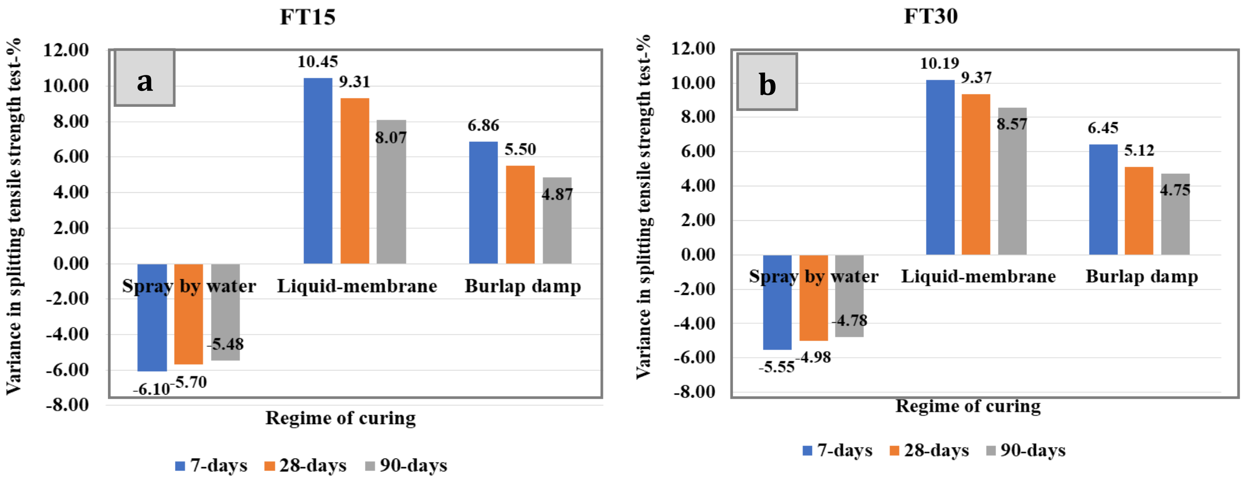

Figure 20. Percentage variance in the splitting tensile strength test for different curing conditions compared with standard-curing for: a) FT15, and b) FT30

Standard-curing (SC) is lower than damp-burlap (DBC) due to the leaching of Ca $(OH)_2$ when the curing water is not saturated. The higher enhancement of liquid-membrane (LMC) than damp-burlap (DBC) may be due to the high ability of the liquid-membrane compound (LMC) to maintain moisture and lessen the loss of evaporation

4. CONCLUSIONS

- The mechanical strength of the sustainable mixture containing WT15 improved by 1.66%, 1.51%, and 1.68% for compressive, flexural, and splitting tensile, respectively, at 28 days for standard-curing (SC) compared to reference-mixture (RM).
- The compressive, flexural, and splitting tensile strengths decrease when using WT30 by 4.97%, 4.24%, and 3.98%, respectively, at 28 days for standard-curing (SC) compared to reference-mixture (RM).
- The mechanical strength of the sustainable mixture containing WT15 improved by 2.08%, 1.92%, and 1.76% for compressive, flexural, and splitting tensile, respectively, at 28 days for liquid-membrane compound curing (LMC) compared to reference-mixture (RM), and by 2.13%, 1.94%, and 1.89% for compressive, flexural, and splitting tensile, respectively, at 28 days for damp-burlap (DBC) compared to reference-mixture (RM), and by 2.91%, 2.63%, and 2.63% for compressive, flexural, and splitting tensile, respectively, at 28 days for spray-water (SWC) compared to reference-mixture (RM).
- The reduction of compressive, flexural, and splitting tensile strength tests for sustainable mixtures (WT15 and WT30) is equal to (7.82, 6.13, and 5.70) % and (7.32, 5.85, and 4.98) %, respectively, for spray-water (SWC) compared to standard-curing at 28 days.
- The best improvement of compressive, flexural, and splitting tensile strength tests for sustainable mixtures (WT15 and WT30) is equal to (11.73, 9.97, and 9.31)% and (11.15, 9.83, and 9.37)%, respectively, for liquid-membrane compound (LMC) compared to standard-curing (SC) at 28 days.
- The improvement of compressive, flexural, and splitting tensile strength tests for sustainable mixtures (WT15 and WT30) is equal to (9.12, 7.23, and 5.50) % and (8.71, 7.01, and 5.12) %, respectively, for damp-burlap (DBC) compared to standard-curing (SC) at 28 days.

NOMENCLATURE

Symbol	Description	Symbol	Description
SRCC	Sustainable roller-compacted concrete	SWC	Spray-water
RCC	Roller-compacted concrete	LMC	Liquid-membrane compound
RM	Reference-mixture	DBC	Damp-burlap
WT	Waste thermostone	SSD	Saturated surface dry
LF	Limestone filler	VH	Vibratory hammer
O-PC	Ordinary-Portland Cement	TP	Tamping plate
SC	Standard-curing	IT-Z	Interfacial transition-zone

Credit Authorship Contribution Statement

Abdullah Al-Ani: Visualization and draft writing, discussion and linguistic review. Zena K. Abbas**:** Conducting and analyzing results and writing references

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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تأثير تقنيات المعالجة المختلفة على تقييم مقاومة الخرسانة المرصوصة بالحدل المحتوية على مواد نفايات

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الخلاصة

الهدف الرئيسي من هذه الدراسة في المختبر هو إنتاج خرسانة مرصوصة بالحدل مستدامة وصديقة للبيئة (SRCC) تحقق المقاومة المطلوبة من خلال استخدام مخلفات مواد البناء مثل وحدات البناء الخفيفة (الثرمستون) كنسبة استبدال حجمي جزئي للركام الناعم بنسبتين (15% و30%)، وكذلك كنسبة استبدال للمادة المالئة بنسبة 50%. بالإضافة إلى المعالجة القياسية تم دراسة ثلاثة طرق معالجة مختلفة: الرش بالماء، المادة المانعة للتبخر، والخيش الرطب. فيما يتعلق بطرق المعالجة، حققت المادة المانعة للتبخر أفضل النتائج مقارنةً بالمعالجة القياسية، يليه الخيش الرطب. من ناحية أخرى، كان أداء الرش بالماء هو الأضعف، حيث أسفر عن نتائج أقل من المعالجة القياسية. أظهرت النتائج أن خلطة الخرسانة المستدامة المرصوصة بالحدل التي تحتوي على وحدات البناء الخفيفة (الثرمستون) بنسبة 15% كبديل للركام الناعم و50% كمادة مالئة، قد حسّنت من مقاومة الانضغاط والانثناء والشد بنسبة 1.66% و1.51% و1.68% على التوالي بعد 28 يوم من المعالجة القياسية، مقارنةً بالخلطة المرجعية. في المقابل، فإن الخلطة التي تحتوي على وحدات البناء الخفيفة (الثرمستون) بنسبة 30% كبديل للركام الناعم و50% كمادة مالئة أظهرت تدهوراً في مقاومة الانضغاط والانثناء والشد بنسبة 4.97% و4.24% و3.98% على التوالي بعد 28 يوم من المعالجة القياسية مقارنةً بالخلطة المرجعية.

الكلمات المفتاحية: الخرسانة المرصوصة بالحدل المستدامة، نفايات وحدة البناء الخفيفة (الثرمستون)، تقنيات المعالجة الخارجية، المعالجة الداخلية.